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TEACHING SCIENCE IN THE SECONDARY SCHOOL

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TO CECIL BURNETT—
AND TO THE THOUSANDS OF HIS COLLEAGUES
WHOSE DEDICATION HAS MADE THEM MASTERS
OF THE ART OF SCIENCE TEACHING

PREFACE

The aim of this book is to present the theory and practice of science teaching on the secondary school level in an integrated fashion in order to help to develop both the theoretical insight and the practical knowledge and skill needed for high achievement in science teaching.

Part I presents the basic problems that must be faced and solved by the teacher if science teaching is to be made effective. These problems are by no means theoretical—they are real and urgent today. Chapter 2 of Part I compares two general methods of science teaching in terms of some of these problems and such goals as the development of critical reflective thought and the acquisition of durable knowledge. This chapter should provide an understanding of the bases of growing criticisms of conventional science teaching. It should also provide a basis for understanding the significance of the considerable body of research which is explored and annotated in later sections of the book—research which supports a notable trend toward a modification of the standard instructional procedures of the past.

Part II is largely devoted to an analysis of the critical problems of science teaching specified in Part I. The contributions of research, experience, and modern psychological theory toward a solution of these problems are presented. Since a great deal of modern practice was inherited from the past, a chapter is devoted to a careful résumé of the history of science teaching in the United States.

The major emphasis of Part III is on the application of theory and research to the practical problems of classroom instruction. Chapters on classroom management, the laboratory, audiovisual aids, and evaluation, for example, are designed to illustrate the consistent application of modern theory and research to classroom problems and operations.

Part IV consists mainly of separate articles written by experienced teachers.

They illustrate the final application to practical classroom operations of some aspects of the theories presented in earlier parts of the book. In short, these chapters represent not what professional educators or teachers think *should* be done, but what good teachers *are* doing today.

Part V, a single chapter, looks more broadly at the status of the profession of science teaching. It is designed to give the reader some understanding of the problems faced by the profession as a whole toward the end that he might join his colleagues in continual self-improvement and in organized effort to improve the profession.

In *America's Resources of Specialized Talent* (New York: Harper & Brothers, 1954, p. 283), Dael Wolfle states

> The brains of its citizens constitute a nation's greatest asset. From the minds of men will come future scientific discoveries, future works of art and literature, future advances in statesmanship, technology, and social organization, in short, all future progress. Since there can be no argument over this proposition, the practical problem becomes one of devising the best means of nurturing the talent which exists in the population.

We who teach science in the secondary schools of America are in an enviable position to locate young persons with special talents and start them toward careers and leadership in science and technology. We cannot do so effectively, however, unless we solve the practical problem "of devising the best means of nurturing the talent" which exists in our student populations. It is my hope that this book will be found helpful in this task and in the task of helping *all* students toward greater intellectual, emotional, and ethical maturity as a consequence of science learnings taught by teachers who know what they are doing—and why.

I am indebted to many for knowing or unknowing assistance in writing this book. I am particularly in the debt of hundreds of master teachers in all parts of the country whose teaching I have observed and whose words I have heard or read. And I owe a strong debt to the inspiration of two former professors, Dr. Samuel S. Powers, Professor Emeritus of Natural Sciences, Teachers College, Columbia University, and Dr. Ernest E. Bayles, Professor of Education, University of Kansas. I want especially to thank Dr. Hubert M. Evans, Professor of Natural Sciences, Teachers College, Columbia University, for reading this book in manuscript and for thoughtful and genuinely helpful criticisms.

R. W. B.

Urbana, Illinois
January 1, 1957

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CRITICAL PROBLEMS OF MODERN SCIENCE TEACHING

What to teach and how to teach it are questions which trouble every thoughtful teacher. Hard to answer for any teaching field, these questions are particularly difficult in science education. To answer them satisfactorily requires understanding of certain changes which have occurred both inside and outside the schools, for these changes have created many critical problems in science education.

In a fundamental sense, this entire book is about these problems and the history, research, theories, and experience that throw light upon them. There are no final answers. Each teacher must determine working answers for himself. But, if the issues and problems are clearly understood and alternatives are thoughtfully considered by enough science teachers, we can be sure that science teaching in America—now in a state of considerable confusion—will steadily improve. This chapter offers an overview of the most critical problems faced by science teachers today and suggests the broad outlines of the science teacher's responsibilities in solving them.

PROBLEMS RESULTING FROM CHANGES IN THE STUDENT POPULATION

Changes in the High School Population

In 1900, only 11 per cent of the nation's population fourteen to seventeen years of age were enrolled in secondary schools. A little more than a half-century later over 76 per cent of the nation's youth in this age group are enrolled. In 1900, science teachers were teaching an elite group, academically and economically speaking. Their task was relatively simple. It consisted of preparing this relatively homogeneous group of capable youngsters for college and of helping them develop a general literacy in science.

Today, the public schools of America are responsible for the education of practically all the children of all the people. Instead of graduating only 2 per cent of the seventeen-year-olds as in 1870, or 29 per cent as late as 1930, the nation's high schools graduated 59 per cent in 1950. To achieve this holding power meant that programs with rigorous standards designed primarily for college preparation of a relatively homogeneous group of academically able students had to be changed. Programs were developed in which standards were made flexible to accommodate the various levels of ability and presumed needs of the heterogeneous population now in our schools. Broad general educational goals ranging from the improvement of leisure to vocational orientation were added to the goals of college preparation and cultural literacy.

Changes in Science Enrollments

Changes in the nature of the school population have brought about changes in the courses offered and more significant changes in the pattern of student enrollments. General science, biology, physics, and chemistry are the standard offerings of high schools today. Many schools also offer a senior science course. This course, generally taken instead of physics or chemistry by the less able students, is designated by such titles as "senior science," "consumer science," or "physical science." Many school systems offer a three-year sequence of seventh-, eighth-, and ninth-grade general science. And, in many small schools which do not have the enrollment or staff to offer all the sciences, physics is alternated with chemistry, or only one or two science courses are offered. Many of the larger schools also offer additional science or science-related courses such as aeronautics, photography, and earth science. Some schools offer advanced courses such as botany, zoology, advanced biology, and advanced physics.

The total number of students enrolled in the basic sciences has gone up since 1900. In that year, about 99,000 students were enrolled in physics courses throughout the nation. In 1949, about 291,500 were enrolled in physics courses. Chemistry, which enrolled 40,000 in 1900, enrolled 412,000, or roughly ten times that number, in 1949. Biology, on which U.S. Office of Education figures have been kept only since 1910, enrolled some 7,800 in that year. But, in 1949,

nearly 996,000 students were enrolled in that subject. Zoology, which enrolled 51,000 in 1910, had dropped to an enrollment of only 5,000 in 1949. General science, on which there are data since 1922, enrolled 394,000 in that year. By 1949, enrollment had gone up to 1,122,000. (General-science figures refer to ninth-grade enrollments only.) Other data could be presented which would make even clearer the fact that we are now enrolling more students in general science, biology, physics, and chemistry than ever before in the nation's history.[1] The enrollment increase is greatest in general science and in biology. This is most clearly revealed by percentage enrollments (numbers of students enrolled as percentages of total high school enrollments).

The percentage enrollment in general science went up from 18 per cent in 1922 (the first year for which data are available) to 21 per cent in 1949. Biology classes enrolled 1 per cent of the total school population in 1910 (the first year for which data are available), 9 per cent in 1922, and 18 per cent in 1949. Percentage enrollments in chemistry have remained static since 1900, 7.7 per cent being enrolled in that year and 7.6 per cent being enrolled in 1949. Physics percentage enrollments have gone steadily down since 1900; 19 per cent in 1900, 14.6 per cent in 1910, 9.0 per cent in 1922, 6.3 per cent in 1934, and 5.4 per cent in 1949.

The fact that percentage enrollments in chemistry have remained static and those in physics have dropped might lead to the assumption that the same high selectivity operates today as in 1900—that the typical student in these courses today is the intellectual equal of the average student of the early 1900's. A moment's reflection will cast doubt on that assumption. Although the percentage enrollments in these subjects have remained the same or dropped, the total school population of the early 1900's was a far more highly selected group than that in today's schools. Remember that only 11 per cent of the youth of high school age were attending high school in 1900. Today, over 76 per cent are in our high schools. The physics and chemistry students of 1900 were probably more homogeneous and in general more capable than the students of today's physics and chemistry classes. Therein lies a difficult teaching problem. It is obviously a simpler task to teach a class of students with relatively common aims, backgrounds, and abilities than to teach a class of students with diverse aims, backgrounds, and abilities.

This problem is greatly accentuated in general-science and biology classes. General science is a relative newcomer to the high school's curriculum and was designed for the general education and orientation of all students; therefore, the burgeoning enrollments in the subject mean that the entire range of abilities and backgrounds of American youth is met in the general-science class today.

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[1] U.S. Department of Health, Education, and Welfare, "Statistical Summary of Education," Chap. 1 of *Biennal Survey of Education in the United States: 1948–1950* (Washington: Government Printing Office, 1954).

The majority of our nation's youth enroll in general science and biology classes. What kind of science program will best meet the needs of these young people, representing as they do the nation's range in backgrounds, interests, abilities? (Courtesy of San Diego County Schools)

This was not true of science classes in the early 1900's. The majority of all the students in our schools now take both general science and biology. (The 21 per cent enrollment in general science—a one-year course—is found by comparing enrollments in general science with total student population in four-year high schools. If one-fourth of the total population was in the ninth grade, a 25 per cent enrollment in general science would mean that 100 per cent of the students take the subject during their ninth year.) Since the schools now enroll the majority of our nation's youth, enrollments in general science and biology represent all of America's youth.

The Task and Responsibility of the Science Teacher

The task and responsibility of the science teacher today, particularly the general-science and biology teacher, are more complicated than those of his predecessors. He is expected to help equip the "dull" and the "bright," the rich and the poor, the college-bound and the laborer-to-be—*all* the children—for personal lives of satisfaction and for the fullest possible contribution to the maintenance and advance of our democratic society. He must provide the finest possible general education in science to all students who enroll in his courses

and at the same time challenge the more capable students and provide them with the level of instruction their abilities warrant.

More specifically, the following problems, which are among the problems explored in the remaining chapters of this book, present themselves as a consequence of the changes in student enrollments in our schools and science courses.

1. What should be taught in general science, which now enrolls the majority of our high school youth?
2. What should be taught in biology, which has nearly the same enrollment?
3. As comparatively few students take physics and chemistry and most students take both general science and biology, should the general-science course (the biology content of which is repeated in the biology course) be abandoned in favor of a physical-science course?
4. If a physical-science course should replace general science, what should be its goals and content? Should it offer a one-semester course in chemistry and a one-semester course in physics, or should it incorporate these sciences, together with phases of geology, meteorology, and astronomy, into an integrated whole comparable to the courses in biology?
5. To be certain that a comprehensive study of both physical and biological sciences is made available to all students, should a two-year sequence of science (one year of biology and one year of physical science) be required of all students?
6. Should botany and zoology be offered, where staff and student interest permit, to parallel elective offerings of chemistry and physics?
7. Should chemistry and physics (and zoology and botany, if offered) represent the equivalent of beginning college courses in these subjects, or should they have a different content?
8. Should students be separated on the basis of I.Q.'s, grades, aptitude tests, or other measures of apparent ability, and two or more sections of each science be offered on different levels of difficulty?
9. Is grouping by apparent-ability homogeneity a sound basis for instructional purposes, or are other factors, such as community of interest, vocational goods, socioeconomic status, and the like, equally or more important?
10. If students are taught in heterogeneous groups, are there ways whereby each student, regardless of ability, can be brought to work near to his capacity?
11. It has been said that the gifted child is the neglected child in our schools today. What can the science teacher do to locate and stimulate the gifted student in science? Should the gifted child be accelerated, cover more ground, work

more intensively, or be encouraged to develop special projects?

PROBLEMS RESULTING FROM CHANGES IN THE MODERN WORLD

There have been many important changes in American society since the early 1900's that have affected education in general and science teaching in particular. The nature of the family as a social unit has changed, and its educative function has generally declined. Many areas of education once considered the proper responsibility of the home are now left by many families for the schools to take care of. These range from homely skills and understandings necessary or desirable for daily living, work, and recreation to social concepts, aesthetic appreciations, and ethics. Should the schools refuse to accept such responsibilities? Are any of these the proper responsibility of the science teacher?

Scientific Achievement and Social Change

America has become a great world power with responsibilities and commitments undreamed of in the early 1900's. This growth has been so sudden and the technological changes brought about by science and invention have been so vast that we are not quite sure what to do with our material power and the world leadership which has been forced upon us. We are no longer even sure about our institutions at home. For, as technological advances have piled precipitously one upon another and as modern forms of communication and transportation have shrunk the nation and the world, the days of relatively stable social organization and leisurely cultural change have been replaced by times of stress and conflict, at home as well as abroad.

In more stable times, such words as "freedom," "democracy," and "loyalty" had basic connotations that were understood, accepted, and revered by the great majority of Americans. Although such terms carry a heavy residuum from our great American tradition and background, they now mean different things to different people. Freedom—yes, but for whom? Loyalty—of course, but what form must it take? Democracy? The concept has always been somewhat different for different men. But for the great majority of the American people—and for many peoples of the world—the term "democracy" has symbolized a magnificent dream, the vision of mankind living and prospering in dignity, in freedom, and in justice, under laws accepted by the people. It is not the same today. Many men have become afraid of the American dream. They have become afraid of ideas evolved by the method of intelligence. In the minds of many men, loyalty has become confused with unthinking conformity. Minds are enslaved in many parts of the world, and attempts at censorship of speaking, writing, reading, and even thinking have increased greatly even here in the United States. In Soviet Russia, and for Communists throughout the world, the very word

"democracy" has been corrupted into its polar opposite—"dictatorship." Even in America, there are some who would change our system of government into a caricature of the American dream.

We now live in an age of continuing crisis.[2] What does this term mean? A society is in crisis when the beliefs, principles, and "rules of the game" that formerly held the people together in common cause and goals have become so tenuous or so poorly understood by the people as a whole that there is dangerous loss in cohesion and common purpose. A society is in crisis when this hard core of common beliefs and purposes has become so small, compared with a large periphery of conflicting beliefs, proposals for action, and contradictions in thinking, that it no longer serves effectively as a commonly accepted value system. In short, a society is in crisis when it is confused in its allegiances and when the old words—such as "freedom," "loyalty," and "equality"—have lost common meaning. Under that definition, we are a society in crisis.

Furthermore, outside pressures intensify our fundamental problem. Russian communism is a threat to democracy throughout the world. But it would be a serious error to confuse the danger of the spread of communism with the fundamental nature of the crisis itself. Clearly, the totalitarian menace must be faced, for the Communist concept of conformity and dictatorship is antithetical to the very nature of democracy and of science itself. But this job can be done only by a mature people who understand the nature of the ideological conflict, who know the danger of that which they fight, and who cherish the values for which they fight. Our relentless opposition to coercion abroad must be waged by an American people mature in its understanding of the nature and goals of democracy. Can the science teacher contribute to this understanding and to the development of democratic skills?

Changes in our value system have not been the only important results of technological change. Advances in science and technology have also created vast opportunities for human advancement in almost every phase of life. But each advance that has been made has been accompanied by problems to be solved. Medical science has increased our life expectancy at birth from forty-five years in 1900 to over sixty-seven years at the present time. This gift of twenty-two years to the average life span has meant, however, that our ideas concerning retirement age, social security, and the place of older persons in our culture required severe overhauling. Ideas once castigated as "socialistic" have become acceptable as appropriate to a capitalistic society in just a few decades. The

[2] "Social crisis" here refers to the term as used by social scientists. See American Historical Association, Commission on the Social Studies, *Conclusions and Recommendations of the Commission* (New York: Charles Scribner's Sons, pp. 5–29; 1934), William O. Stanley, *Education and Social Integration* (New York: Bureau of Publications, Teachers College, Columbia University, 1953). (Stanley's outstanding book is entirely devoted to this problem and its implications for education.)

social changes effected by scientific advance forced this reshaping of our concepts and mores.

Other examples could be cited. In each case, a purely scientific advance has been followed by technological changes which, in turn, forced quite drastic changes in social concepts, organizations, and value patterns. Looking backward in time, it is easy to see this "chain reactivity" of science and invention on our lives. The question facing science teachers is whether it is possible to look ahead, to predict with fair accuracy the influence that recent scientific advances will have on society, and to help young people to accept and plan for the changes which will occur. A brief comparison between a historical change and one just now gaining momentum may be useful in understanding the chain reactivity of science and technology. The internal-combustion engine and atomic energy will serve for the comparison.

In certain important particulars the controlled release of atomic energy is not different from other scientific developments. It was achieved by the rigorous "common sense" that is the scientific method of inquiry. It resulted from an attack on fundamental problems in nature by hundreds of men working all over the civilized world over an extended period of time.

As fundamental knowledge was wrested from nature, and the controlled release of nuclear energy became a reality, there followed a chain of developments—still continuing and to continue—that were the technological, engineering, and social derivatives of the basic scientific achievements.

The bomb was but one of these derivatives. Intensified in time of global war, the final search for the controlled release of nuclear energy was focused on the engineering problem of designing a weapon. That weapon, despite its awesomeness, is an engineering gadget. It is comparable to the first internal-combustion automobile in that both represent merely an early engineering application of certain basic scientific truths. In both cases, the specific application is but one in a chain of technological applications of the same set of scientific findings to an ever-widening area of human activity.

The internal-combustion engine released a chain of technological developments that has resulted in highly mobile devices of all sorts. But the chain did not stop with the automobile, the airplane, the locomotive, the jeep, and the tank. These, in turn, required highway networks, meteorological apparatus and know-how, automatic block signals, radar, complicated machine tools, and the like.

And technological developments always have social consequences. The internal-combustion engine not only created a chain reaction of technological developments but produced, as well, vast changes in social processes.

Agriculture, for example, became mechanized, and as a result the food problem in this country became less a problem of producing than of getting rid of the produce. How to adjust our economic structure and concepts so as to take advantage of the possibilities of better living for all, without at the same time destroying certain cherished values, such as those of individual choice, freedom

from unnecessary governmental controls, and so forth, became problems of moment.

The automobile increased the farmer's mobility and brought him into contact with other ways of living, which changed his conception of living standards and created a new market for thousands of manufacturers.

Concepts of thrift and financing were modified. New problems of resource management were encountered. A powerful political force and lobby were created. New norms and value systems were erected.

In these and in other ways, the structure and concept of American democracy were affected and affected deeply. And—in a sense—all because the farmer had a car and a tractor.

The requirements of public education were affected at the same time. They were affected not superficially but basically, for the internal-combustion engine had deeply affected American life. And education is always an expression of the life of a society as it attempts to induct its youth, maintain its values, and advance.

Atomic energy is on the high level of the internal-combustion engine, the wheel, and the radio in its potential effect on technology, social processes, and value systems. It is a pervasive new development that has already had tremendous impact on the thinking of man and on the course of his destiny. Many devices and techniques are flowing and will flow from the fount of this basic discovery and its development into usable form. To many persons it seems imperative that teachers assess the controlled release of atomic energy and understand both its nature and its present and potential effects on man and his institutions. But is this the responsibility of the science teacher? As the interpreter of science to young people, should he keep abreast of technological developments? Of the impact of such developments on society? If the answer is yes to the general question, it would seem to require an emphatic yes for atomic energy because of the prodigious power of the atom both for good and for evil. The constructive possibilities of atomic energy must particularly be emphasized, for they are still unknown to the average man and require general understanding by the people if they are to be realized as fully as possible.

Control of atomic energy has been achieved at a time when society is already creaking under the weight of other technological advances that have outstripped its social understanding and engineering. At a time when we are beset with numerous proposals designed to accommodate society to recent technological changes, we now must contend with a new scientific achievement so powerful as a social force that it must be ranked with the two or three most fundamental discoveries in the history of mankind.

The Problem of the Scope of Science Teaching

There are dangers in accepting educational responsibility for dealing with the social implications of science. The chief danger rests in the fact that thorough knowledge of science *and* of its relation to society is required. The science

teacher may be superficial in his treatment of this complex subject. Such superficiality is not uncommon in the schools. Since 1945, for example, it has become increasingly popular to speak of our time as the "atomic age." The term is generally used to symbolize man's unprecedented power for advancement or destruction. But there is danger that the term will become a cliché. During World War II, school after school developed courses on "the air age" that were as thin in meaning and as lacking in vitality as the term was shopworn. Textbooks were written and used that contained only more or less technical analyses of the kinds of information desirable for the pilot but essentially worthless for the average citizen.

The term "air age" symbolizes a world of national states shrunk to geographical unity by the fact of the airplane. It represents a period of history in which new social insights and skills are necessary for civilized survival. It suggests a time in which man has created the mechanistic base for heights of human betterment and advancement never dreamed of in an earlier day. At the same time, it epitomizes a shrunken world where mass suicide becomes all too possible.

The modern world requires a reassessment and modification of instruction in the high schools that will enable young people to develop the intellectual, emotional, and ethical maturity required by a period of human existence which is heavily influenced by modern means of communication and transportation and by unprecedented energy resources. Seen in proper perspective, "the atomic age" is but another term for this same modern world of swift social change—with the addition, of course, of the vast power of the atom and its chain reaction on social, economic, and political issues.

It is within this setting of swift social change and of crisis in our value system that the American teacher must assume his professional responsibilities. He must be the representative of the best in the American dream for the youth under his charge. He must help young people to such vantage points of maturity that they, too, will see the vision that has made our country great.

Many people believe that the science teacher has special and heavy responsibilities within this task. He, like all teachers, is a representative of democracy in the classroom. In addition, he must represent the philosophy and traditions of science to his students. And the traditions and basic philosophies of both democracy and science coincide in their insistence on freedom of the intellect, on the validity and power of the method of intelligence, and on the corrosive effects of all forms of restriction of thought. Finally, science understandings necessarily underlie social understandings. Some knowledge of the scientific aspects of atomic energy is required for sensible consideration of the problems of its development and control.

The responsibility of the science teacher in this age of crisis and change may therefore go far beyond that assumed by the science teacher in former years. Should he accept the larger responsibility, or should he restrict himself to teach-

ing science as a discipline, without reference to its interaction with other social forces? If he accepts the larger responsibility, he should know that his task is made difficult and complex by the scientific and technological developments of the past few decades and the social, economic, and political problems which these scientific achievements have produced. In addition, of course, the science teacher must still provide a sound foundation of knowledge in the organized fields of science for those young people whose aptitudes and interests bear the promise of leadership roles in the scientific and technological age so well epitomized by the term "the atomic age."

The preceding discussion has dealt with some important aspects of social change. It has stated certain broad responsibilities that such changes may have created for science teachers. The need for sound instruction related to these changes is clear. The question whether the science teacher's classical role of teaching a rather technical discipline should be enlarged to include responsibilities for instructing young people in the science aspects of social problems is debatable. But the following questions are particularly critical and must be faced by each science teacher.

1. Does the science teacher have the responsibility of demonstrating the validity of the method of intelligence in the solution of problems?
2. Should science instruction deal only with the method of intelligence as applied to science problems, or should the science teacher illustrate the validity of the approach as applied to nonscience problems?
3. As science and technology are the primary moving forces in modern social change, does the science teacher have the responsibility of cooperating with his teaching colleagues in dealing with the problems of fostering democratic, orderly, uncoerced change?
4. If it is true that infringements of freedom of thought, inquiry, and expression impede the advance of both science and democracy, should science teachers incorporate into their teaching analyses and examples of the negative effect of restriction of freedom on both science and democracy?
5. Should science teachers plan their offerings alone, or should they plan with their colleagues in order that their instruction might form a more cohesive and integral part of the total instructional program? The presumed logic in such cooperative work is that each discipline or subject field has a particular and important contribution to make to basic problems and that these contributions can best be made through the fullest possible planning and integration of instructional programs.
6. Should science instruction deal only with the facts and

principles of science, or should it deal as well with the philosophy of science—a philosophy that is remarkably synonymous with that which underlies American democracy? Might such instruction become an important bulwark of democracy?

7. Should science instruction deal with such topics as atomic energy, which are rather complex from a technical point of view but which have created many social problems that the people should help answer if their form of government is to remain a democracy?
8. What level of technical understanding is really required for sound consideration of policy decisions concerning such things as atomic energy? In other words, is it practicable to assume that the people can still direct their destinies in an atomic age? And can the science teacher help to make the answer an affirmative one?
9. If it is true that our society is in crisis, is there danger that each teacher of a particular discipline who refuses to look beyond his subject may help to deepen that crisis? Does the science teacher have a responsibility to look beyond his subject to the world about him and join his colleagues in attempting to create a more stable world in which decency, freedom, justice, and dignity abound?
10. Might the very attempt to do these things be dangerous and impracticable—an effort to be "all things to all men"—and result merely in confusion, poor teaching of science, and even dangerous misinformation being given to students?
11. Might the teacher of science equip himself sufficiently beyond his discipline (in such fields as philosophy, history of science, history, and political science) to relate his science instruction to the affairs of the world?
12. As this is an age of specialization, might it be better for science teachers to restrict their offerings even more narrowly to science as science than they have done in the past? This question rests on the argument that advances in science have made it impossible to treat even all phases of a particular science discipline, let alone attempt to relate it to nonscience fields.
13. Might it be well for the science teacher to give up trying to cover all aspects of a science and to work for thorough understanding of limited areas rather than for superficial coverage?
14. One critical problem resulting from our scientific advance is that we face a severe shortage of scientifically trained manpower (see Chapter 15). As our very security as a nation is jeopardized by this shortage, might it not be wise for science instruction to devote itself primarily to the interests

of preparing above-average students as thoroughly and efficiently as possible for science careers?

15. Might such a preoccupation with the apparently gifted result in the loss to science of many competent research workers and technicians because their potential for such work was not demonstrated in their early high school years?
16. The critical manpower shortage in science includes a severe shortage of competent science teachers. What can the science teacher do to increase the prestige of his profession and the number of young people who will enter it? These problems, too, will be explored in later chapters of this book.

PROBLEMS RESULTING FROM ADVANCES IN PSYCHOLOGY AND PEDAGOGY

Knowledge in psychology and pedagogy has advanced just as has knowledge in other fields. We know much more about such things as motivation, learning, transfer of learning, and a wide variety of other pedagogical problems than we did in the early 1900's. But because human beings are complex, and because many factors necessary for controlled research are intangible and at present cannot be controlled, our knowledge in these areas is still woefully inadequate. A good deal of educational practice therefore rests on untested assumptions rather than facts. On the other hand, there has been sufficient research to give us a sound basis for improving school practice, including that in science education.

Where, then, lie the problems? Some result from the fact that changes have sometimes been made on the basis of certain truths or apparent truths revealed by research and tested experience without comparable changes in closely related areas. Such changes create particularly crucial problems when a particular practice is changed without modification of another of which it is part and parcel.

An example from the elementary schools that has negatively affected science education may be useful. Studies have generally shown that there is little or no gain in subject-matter knowledge or skills when a child is failed and held a second year in a grade. These studies also show that such practices tend to create emotional-social problems which negatively affect the child's learning in many important particulars. Therefore, many schools have a policy of rarely failing youngsters in the elementary grades. But suppose a child in the fourth grade has shown that he has little understanding of fourth-grade arithmetic. He is placed in the fifth grade nonetheless. The philosophy of "automatic promotion" should include the view that the fifth-grade teacher should work with each student at his level of understanding and accomplishment. This means that the fifth-grade teacher would start with fourth-grade arithmetic for the child in question, moving on to fifth-grade work only when the child is ready for it. But fifth-grade teachers are accustomed to teaching "fifth-grade" arithmetic, so

the child who could not understand fourth-grade arithmetic has even more trouble in the fifth grade. He is pushed to the sixth, seventh, and eighth grades, and then on into high school. By this time, he is convinced that he is a "mathematical moron," and, because of his insecurity in dealing with simple arithmetic problems, he will probably hate physical science as well as mathematics.

Another example is in the field of evaluation. Students often become grade conscious to such an extent that they work only for grades and care little about learning and understanding. So some schools have abandoned conventional grading systems and have used descriptive reports instead. But students who worked only for grades were then expected to work hard for the satisfactions of understanding. This might be good except that programs and courses, often including large amounts of material that were of little intrinsic worth, were kept as they had been before the whip and reward of grades were removed. Without this challenge, and with nothing to replace it to motivate learning experiences, students often quit working. Although the soundness of conventional grading systems is open to question from a psychological point of view, it cannot be abandoned unless the curriculum it traditionally bulwarked is made more vital, worthwhile, and interesting in the student's eyes.

Still another example is that of extracurricular activities. The schools of the early 1900's had few activities beyond those of the academic classroom. But as it became apparent that all-school functions, clubs, and out-of-class activities had great educative values, these were added to the curriculum. Without question these have been for the most part desirable. But many teachers have become concerned whether or not the tail is not now wagging the dog in many schools. The amount of time and energy devoted to extracurricular activities, however valuable these may be in themselves, has taken a large amount of time from academic studies. What is the proper balance between these things?

But the most important problems created by advances in psychology and educational research are those involved in assimilating the results of such research and developing a consistent and workable philosophy for sound teaching.

For example, it was once thought that children tended to be lazy by nature and that school subjects should be sufficiently difficult and even distasteful to "discipline" the students' minds. Few, if any, believe this today, but a fair amount of school practice goes on as if the notion were still accepted as valid. We now know that young people are not lazy unless they are suffering from poor health. Apparent laziness in connection with school work results from boredom, feelings of insecurity, the weight of outside interests and responsibilities, and many other things. But the problem the teacher faces is that of finding the reasons for the apparent laziness and working on the causes rather than assuming that the symptom expresses the nature of the child. To do this requires both understanding and high skill.

As another example, we now know that discipline problems have several causes, which may be categorized under the following four general headings.

1. Boredom resulting from an unstimulating school environment or a curriculum that makes no sense to the learner
2. Sheer animal spirits (the conventional classroom being hardly the ideal environment for young people in a physical sense)
3. Failure or sense of failure, with consequent feelings of aggression
4. Attempts to gain recognition on the part of youngsters who have not been successful in gaining the feeling of belongingness through socially approved means.

The hickory rod and all that it symbolized in authoritarian techniques was in a measure effective in maintaining classroom discipline. But we now know methods far more conducive to effective learning. Research is rather clear on the nature of classroom discipline that fosters effective learning. A democratically operated classroom, for example, is superior to either an autocratic or anarchic one. But the operation of a democratic classroom requires more planning and more complex teaching skills on the part of the instructor. Herein lies a group of problems that the science teacher must resolve if he wishes his teaching to represent the best that is known.

Psychological research and investigations in science education have produced a large number of facts and presumptive data that can lead to better classroom teaching. They have also provided partial answers to such questions as the following:

1. Are teacher demonstrations superior to individual laboratory work?
2. Does conventional science teaching lessen superstitions in the learner?
3. What differences in learnings result from the use of single textbooks, compared with the use of a variety of references?
4. Do different practices of science teaching result in different levels of critical thinking?
5. What practices develop science learnings longest retained after the student completes a course?
6. Is it possible to teach in such ways that science learnings are transferred to the out-of-school life of the learner?

These are typical of the many problems which have been investigated and on which there are results worth analyzing.

THE GOALS OF SCIENCE TEACHING IN TODAY'S SCHOOLS

Following are certain propositions concerning the functions of science teaching in today's schools. They rest on the preceding analysis. Debatable as these viewpoints may be, they can serve as a basis for reflection and of choosing between

alternatives. Whether the science teacher accepts or rejects these propositions is not as important as that he build a consistent philosophy concerning his profession and that he develop ways of implementing his philosophy in consistently good teaching.

We assert that a primary job of the science teacher consists of relating science to the progressive refinement of the democratic way of life. This is the task of helping young persons become aware of the forces of their environment so that they may think and act, control and select more intelligently. It is the task of aiding young people to attain a position of perspective on the place of science and scientific research in modern society. Since our dynamic modern society is to a great extent the result of modern science and invention, the science teacher must share with his colleagues in other disciplines the responsibility of preparing young people for satisfying and socially useful lives in a swiftly changing scientific world. In order that scientific advance may be maintained and even accelerated it is necessary that the majority of our young citizens understand its nature and requirements. It is also necessary that all those who have sufficient potential abilities and interest to prepare for careers in science be given full opportunity to do so. Science teachers must be the exemplars of the philosophy and the critical method of inquiry of science for their students. Not enough science teachers have assumed this role in the past; the products of our science classes demonstrate this. There is no aspect of human activity that organized science has not modified. But, intellectually, we could hardly be called a scientific people. The mind of modern man is a hodgepodge of superstitions, anachronisms, and scientific beliefs, with little awareness of inconsistency or incompatibility. Our society has become so integrally scientific in the material sense that the expression "impact of science on society" has become almost meaningless. American society is scientific in the material sense. It is up to the science teacher to help make it so in the intellectual sense.

In 1885, Jules Henri Poincaré, the great French mathematician and scientist, stated, "Science is built up with facts, as a house is with stones. But a collection of facts is no more a science than a heap of stones is a house." Could it be that we have been so preoccupied with teaching the facts of science that we have been oblivious to the larger and more important edifice of science itself? Science teachers should be aware that their responsibility as the representatives of science and democracy in the classroom is not discharged by the process of hammering home the facts of science nor consummated with the evidence on standardized examinations that their students can, indeed, recall for the moment the facts as they have been taught.

The edifice of science is built with facts, but it is the proper and judicious use of those facts and the employment of the rigorous intellectual process by which the factual can be distinguished from the illusory that is the proper business of the inhabiters of that structure. It is only as that business is carried on that science, and, indeed, democracy itself, can advance. Truth and the

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freedom to find truth by the method of intelligence are threatened today by exponents of totalitarian viewpoints whose allegiances and methods are antithetical to the very nature of science and democracy. The survival of the free world and its institutions, including organized science, is heavily dependent upon an informed citizenry which has come to understand and treasure the meaning of freedom, the method of intelligence, and the method and philosophy of science. Herein lies the science teacher's chief job today.

The over-all responsibility of science teachers in a great democracy is therefore to challenge, stimulate, guide, and assist young people to develop the understandings, critical abilities, attitudes, and viewpoints that represent the best in the scientific and democratic traditions. Some instruction must be focused upon the urgent problems of personal and public life, for ours is a society where the people must determine the formation and execution of policy in matters that affect them. The science teacher's responsibility in cooperation with all teachers is to make his students so much at home in the house of science, as Poincaré saw it, that they will reside in it, contribute to its constant improvement, and defend it against all detractors. This job is the same whether our students become professional scientists in the technical sense or simply skillful, scientific-minded artisans in the all-important task of advancing the causes of freedom and humanity at home and abroad.

College Preparation

There are several aspects to the science teacher's responsibility. For one thing, we who teach science at the secondary school level must join forces with our colleagues who teach at the college level in improving the total offering in the organized sciences for those of our students who will continue their work in institutions of higher learning. Sound college preparation is an essential and fundamental part of our responsibility.

Functional Knowledge

Secondly, we must wisely select and soundly organize the content and experiences of our instruction so that facts, principles, and broad understandings that are fundamental to sound human living in the modern world will be learned—really learned—and retained. We must be sure that our students do not leave our courses with but a smattering of facts sufficient for filling in blanks on standardized tests but unusable in the affairs of life and, therefore, soon lost in the limbo that receives many inert academic learnings. *Our students, generally speaking, are capable of learning far more than we commonly have taught.* But the pace at which many science teachers race over facts, logically and statically organized but essentially alien to the experiences, interests, and needs of young people, must be questioned on the ground that at best it produces verbalists. Functional and lasting scientific knowledge is required for satisfactory modern living. Sound personal living and wise decisions on public policy both depend

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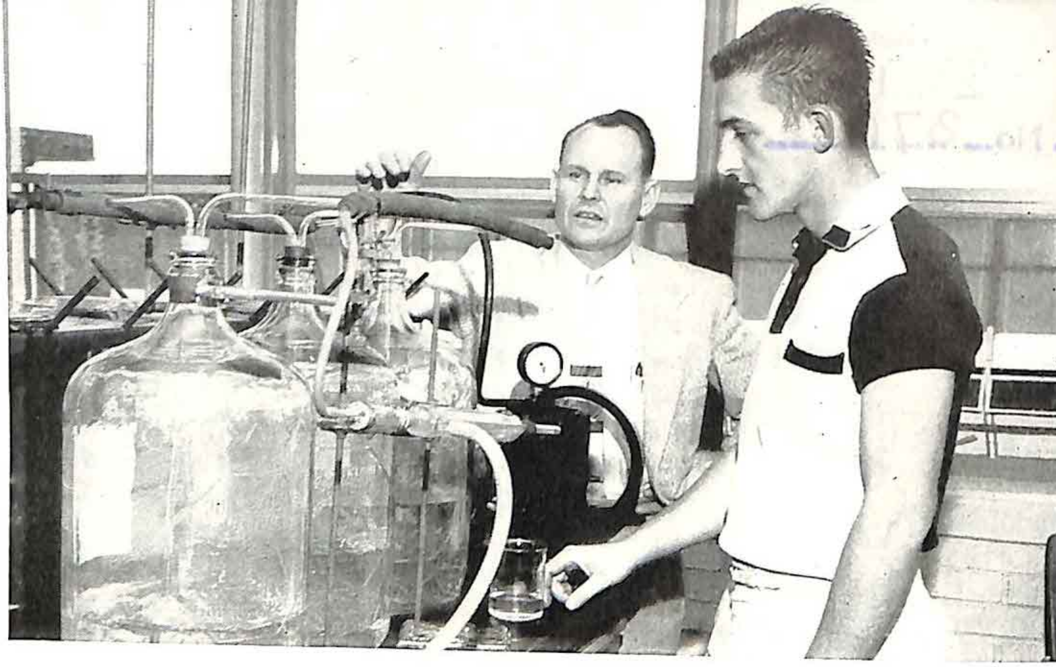

Sound college preparation is one of the most fundamental responsibilities of the science teacher. It is now more crucial than ever before, because of the national shortage of trained scientific talent. These high school students are participating in a sea-water distillation project. Knowledge of the practical applications of science to living problems gained from such activity is important in stimulating the responsible, critical thinking required in advanced studies. (Courtesy of San Diego County Schools)

We must be sure that our students do not leave our courses with a mere smattering of facts unrelated to life and soon forgotten. Will individualized analysis, such as the diet study this girl made, help to bridge the common gap between school and life? (Courtesy of Atlanta Public Schools)

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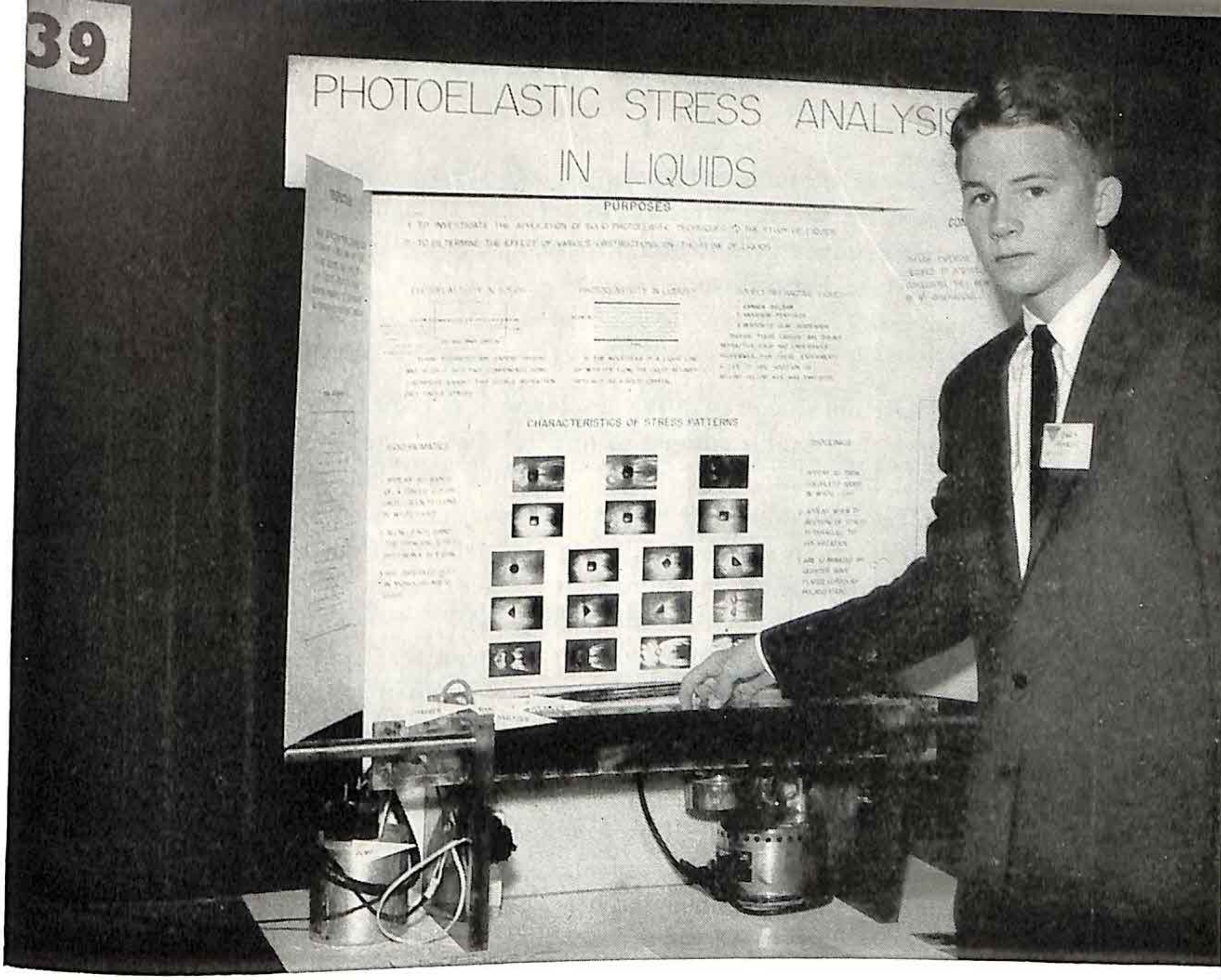

Perhaps our greatest responsibility lies in developing the powers of critical thought and independent analysis in our students. This National Science Fair project of a student at Atlanta's Northside High School represents a power of critical inquiry and reflective thought too commonly left undeveloped by the nation's science teachers. (Courtesy of Atlanta Public Schools)

in part on knowledge and understanding of natural science. Anti-intellectualism, ignorance of psychology, and mental laziness have all contributed to the retention of superficial science teaching that is demonstrably failing to inspire students or produce usable knowledge. These forces must be combated individually and collectively by the nation's science teachers.

Critical Thinking

But the responsibility of the science teacher does not stop with imparting functional knowledge. Even more important than the facts we teach are the abilities we may develop that will enable our students to engage, throughout their lives, in the process of self-education and in the judicious and critical use of facts for the betterment of their personal lots and the lot of mankind. We know all too little about the processes of critical thinking and how to develop them. But this must not stop us from using the best that is known toward the

development of increased power of reflective thought in our students. Some aspects of the process of critical inquiry and thought are quite well known and have clear imperatives in the instructional process. We are irresponsible if we neglect these imperatives.

Emotional and Ethical Maturity

We dare not stop even at the development of critical thinking, for our students are more than brains encased in physical shells. They are total living personalities that hate, fear, hope, aspire, and love. It is impossible to teach just the brain. The individual is emotive and valuative as well as intellectual. It is possible to teach in such ways that our students will come increasingly to value the right and to shun the wrong. But it takes thought and planning. It is possible to teach in such ways that our students will develop in emotional stature and in allegiances to the values and ethical systems that are deep in the main stream of American democracy and the great religions that have given direction and substance to human events throughout history. But it takes doing. The emotional and ethical well-being of our students is in our hands to the same extent as their intellectual training. And we shall be ineffetive in our efforts toward intellectual development if we forget or ignore the emotional and ethical phases of our students' lives; our students cannot ignore these integral aspects of their personalities, even if their teachers can.

These—in broad strokes—are the goals of modern science teaching. Indeed, they are in general the goals of all good high school teachers. They are pervasive goals, and they require, for accomplishment, some understanding of modern society, of the setting in which the science teacher must find his proper role. Although the setting is obviously the same for all teachers, regardless of their fields of specialization, it has particular import to the science teacher, who must stand as exemplar and representative of the twin concepts of science and democracy.

Albert Einstein once stated, in reference to the control of the atom, that the problem resides in the hearts and the minds of men. This is true of all our basic problems. We who are teachers deal with the hearts and the minds of children soon to become men. If we discharge our great responsibility wisely, these children, become men, will advance both science and democracy—and the cause of freedom and decency throughout the world.

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TWO CONCEPTIONS OF SCIENCE TEACHING

It is patent that no one can teach what he does not know. To teach science, and teach it well, one must be able to lay the textbook aside and make his science come to life for the students. This cannot be done unless the teacher has mastered the discipline he teaches.

But there is more to any profession than intellectual mastery of the facts and principles of the field. There is art and technique. The medical doctor must apply his knowledge of the human body, disease transmission, and drugs to the diagnosis and care of human beings. The complexity of the human body and the vagaries of symptomology require that he develop high skill in the arts and techniques of medical practice. Stereotyped notions of what to do are highly dangerous. No set of easy answers—no bag of tricks—will suffice. Each patient is somewhat different from all others and must be considered as a special case.

A similar situation exists in the profession of teaching. Sound mastery of science disciplines is not sufficient for effective teaching of young people. The child is complex. The process of learning is complex. The teacher must add to his understanding of science an understanding of young people and how to work with them in such ways that his instructional goals are achieved. He must master the art and technique of guiding learning activities. Stereotypes are as dangerous in the teaching profession as in the medical profession. The teacher who assumes that pat answers can be given to the complex problems of teaching young people is doomed to failure, for each child is different from all others and must be considered as a special case. The teacher, no less than the doctor, must be a diagnostician and highly skilled in resolving the problems of his work.

Perhaps the most embarrassing question that can be asked a teacher by one of his students is, "Why do we have to study this?" If the teacher has really thought through what he is teaching, sees his objectives clearly, and is teaching in a manner that is producing durable and functional learnings, students are not likely to ask such a question. And, if they do ask, the teacher will have no difficulty in responding with candor and with conviction. But it is difficult to attempt to explain to a student what possible advantage there may be in his study of science when the teacher himself does not really know. We owe it to our students to examine what we have been teaching and discover what is fruitful and what is deadwood.

Effective examination requires clarity concerning the criteria to be applied. Good practice can be distinguished from bad only in terms of what students learn and how well they learn it. Unless we know what students should learn from their science courses, we can hardly determine how effective a particular practice is. The preceding chapter suggested a point of view on science teaching and presented problems for the consideration of the reader. A tentative position on these problems will help the reader view the two categorical patterns of science teaching to be explored in this chapter with perspective.

One type of science teaching to be analyzed has been common in American high schools for many years. It is here called "the old," for want of a better term. The other type of science teaching is increasingly finding favor in American high schools as teachers have become acquainted with modern psychology and the results of methodological research. It is here called "the new."

It should be recognized, of course, that no single program can be designated as "old" or "new." The terms are useful only for comparisons. The most hidebound conservative will find some of his techniques employed in what is here called "the new." The most starry-eyed teaching radical will agree that he employs many of the procedures that are here designated as conventional. The teacher in training will remember practices employed by his former science teachers that will encompass both what is called "old" and what is called "new." The new differs from the conventional in the matter of emphasis. For clarity, the differences will appear greater in this account than they commonly are in reality.

These two types of science teaching are different because the conceptions of the teachers who practice them are different. Their basic goals are doubtless much the same. But their views on how to achieve these goals are different; therefore, their practice of the art of teaching is different. By observing these differences, the reader will find that different answers to the problems explored in the preceding chapter have been given by different teachers.

Basic elements of the older programs will be presented first. Then, the two types of science teaching will be compared under two main headings: (1) practices designed to develop scientific attitudes and abilities; and (2) practices designed to develop functioning understandings of science facts and principles.

Under each heading will be presented (a) the common criticisms of conventional programs that gave rise to the development of the newer practices, and (b) the basic elements of the newer practices, together with a somewhat extended analysis of their rationale. Documentation on the strengths and weaknesses of these practices will be provided in later chapters that deal more exhaustively and in greater detail with specific phases of the instructional process.

BASIC ELEMENTS OF THE OLDER PROGRAMS

Whatever science courses the student takes, the conventional instructional procedures are much the same. A textbook is employed, and each student is expected to study the text and to learn its contents. The teacher's task is to present the science to the students, clarify points of difficulty, challenge the students' thinking, assist the students in exploring the meaning of the science to their lives and to modern communities, and to do everything possible to ensure that the facts and principles as presented by the textbook are learned.

Natural phenomena are presented by demonstrations, usually by the teacher but often by individual students or student committees. These demonstrations generally employ standard apparatus produced by commercial firms which specialize in studying the need for school science equipment and supplying materials that meet the need. The demonstrations serve to provide visual impact to the textual account of science phenomena and to illustrate basic principles.

Student projects are generally encouraged. Students are stimulated to make special studies through the use of various reference books and to construct and demonstrate models and apparatus in areas of their special interest. Additional opportunities for following special interests are often provided through science club and other extracurricular activities.

Individual or group laboratory work is generally provided in physics and chemistry, somewhat less commonly in biology, and occasionally in general-science courses. A common procedure is to set aside two days a week for a double period of laboratory work. Laboratory manuals are usually provided, and the student is required to complete a set of standard "experiments" during the course of the year. In biology, the laboratory is typically used for careful observation of parts of plants and animals and, to a lesser extent, for occasional experiments (on photosynthesis and on digestants, for example).

Field trips are variously used; students take short trips to observe the applications of the science they are studying in their local communities and, in biology, to study living things.

Evaluation of the student is chiefly by paper and pencil tests constructed by the teacher and by standardized examinations. Essay tests are sometimes used, but evaluation is overwhelmingly by formal objective tests in which the student is expected to check the correct answer to a series of true-false, multiple-response, matching, or similar objective-style test items. Grades are often raised or lowered

on the basis of projects done, accuracy in laboratory work, effectiveness and accuracy in classroom recitation, and the apparent degree to which the student is working up to his own capacity.

The most notable feature of the older programs is that the textbook forms the program. Modern textbooks are generally excellent textbooks. They provoke thought, they present interesting problems, they are lucidly written, and they offer many examples of how science is related to life. Good teachers in the older programs add to the textual account from their own experiences, draw on the students' experiences, and develop an interesting and challenging course. But the easiest way to determine just what is done, what is covered, and how much time is spent on any particular topic in the conventional program is to examine the text being used. The textbook determines the program and, to a great extent, how it is carried out.

PRACTICES DESIGNED TO DEVELOP SCIENTIFIC ATTITUDES AND ABILITIES

Criticisms of the Older Programs

What are the alleged defects, so far as the development of critical thinking and scientific attitudes are concerned, in the older programs we have briefly described? How do the proponents of the newer programs look upon these conventional attempts to develop scientific attitudes and methodological abilities in our students? Their viewpoints run somewhat as follows.

The evidence, say the critics, is far from convincing that conventional programs have often achieved the goal of developing critical thinking or even made notable progress toward it. Various writers have analyzed the situation, and their viewpoints are remarkably consistent. One of the more recent statements is that of Kruglak. He states his essential thesis as follows:[1]

> If the scientific method were a known sequence of steps, then it would only be necessary to memorize them and grind out the solution to any problem whatsoever. With the same set of data the same conclusions would invariably be drawn. Every high-school science teacher will testify that the majority of pupils can recite the successive steps, which his textbook describes as *the scientific method,* without ability to carry out even the simplest independent investigation.

Actually, it is difficult to define "scientific method" except for purposes of gross identification and discourse. True, we know many of its ingredients. But we have been utterly naïve, say the critics, if we have felt that accounts of the great scientists, discussions of scientific method, and typical recitation and labora-

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[1] Haym Kruglak, "The Scientific Method and Science Teaching," *School and Society,* 69, No. 1787: 201 (March 19), 1949.

tory practices would result in increased critical power on the part of the student. Bridgman's famous definition of the scientific method is as sound as any in its reflection of the myriad things that go on in the activities of the scientist at work. He stated, "The scientific method, as far as it is a method, is nothing more than doing one's damnedest with one's mind, no holds barred."[2] This definition is obviously too general to be of any worth except—as it was intended—as an antidote to the stereotyped conceptions of scientific procedures of inquiry apparently held by many science teachers both in high school and college. Such an antidote is needed, say the critics. These traditional conceptions have been notably ineffective in producing critical and incisive abilities even—outside the narrow confines of their fields of expertness—among those who prepare for scientific vocations. They have certainly failed among the great majority of our young people who would profit from experiences that would give them increased power with which to tackle the problems of daily living.

If we are to be honest, say our critics, we must admit that the usual science teacher has given little sustained thought to how to develop critical thinking abilities—or, for that matter, what, in any precise or usable sense, makes the difference between a critical-minded person and one whose thought processes are sloppy. The teacher vaguely assumes that the textbook and the laboratory will get the job done—even though research on the transfer of training since the 1908 studies of William James and the early studies of Edward Lee Thorndike have consistently demonstrated the falsity of this assumption.

The proponents of the newer programs ask us to examine what is being done in our classes and laboratories. We are facing the criticism that what we will observe is well designed to develop concepts of authoritarianism but is remarkably ill designed for developing critical-mindedness or emotional and intellectual maturity in our students. Some of our critics have gone as far as to say that the typical science teacher has done more to thwart the development of critical thinking processes than any other teacher in the school. An alarming indictment, surely!

Just what is our critics' argument? It runs as follows:

The conventional science teacher appears to feel somewhat honor-bound to cover the material of the text he is using. He feels somewhat guilt-stricken if the end of the semester is looming near and he has several units yet uncovered. Although it is obvious that the teacher can "cover" at best but an extremely small portion of the science he is teaching (in terms of the basic source materials of that science), he nonetheless struggles valiantly to sweep over at least the majority of content found in the textbook he employs. This has typically provided a heavy emphasis upon the acquisition of facts rather than an emphasis upon increasing the power of students to obtain facts or to use them intelligently in making decisions. Attempts to cover the many facts of science have allowed

[2] P. W. Bridgman, "Prospect for Intelligence," *Yale Review*, 34:450, 1945.

students little time for the development of real understanding or the exploration of variant and conflicting viewpoints. The typical teacher runs roughshod over doubt and skepticism. *Yet, doubt and skepticism are essential ingredients of the scientific temper and should be nurtured and directed, not ignored or stamped out.*

Secondly, say the proponents of the newer programs, conventional teachers often deal with facts to the virtual exclusion of real problems. They seldom even recapitulate the storms, controversies, and wrong answers that were, historically, the experience grounds for the development of the scientific abilities of many men of science. The "problems" in conventional science teaching are textbook problems, neatly identified, developmentally strait-jacketed, and baldly answered under a single-track, forced draft series of steps and progressions. These are as useless for the development of critical procedures of thinking as they are atypical of real-life problems.

Third, say the critics, the very nature of our subject matter, a body of organized and tested knowledge, admits of little or no argument—*as it is commonly taught*. The teacher of social science cannot assign readings on our present foreign policy and expect to teach a particular viewpoint as tested truth. Consequently, he has the opportunity, at least, to assist his students to increase their power to identify problems, structure them, check viewpoints for agreement with known facts, pull out the red herrings, and check personal biases. Not so with the science teacher when he deals exclusively with the body of factual material he calls "science" and considers it something to be memorized rather than analyzed. E always equals IR, and let there be no mistake about it. It is a principle to be learned as if it were fact. Actually, as usually taught it requires no reasoning at all in the psychological sense; for there are no decisions possible here, no false issues, no red herrings, no choices. In short, the memoriter learning of this principle, or that S equals $\frac{1}{2}\ at^2$, or that the ammonium radical has a valence of one, or the Mendelian laws admit but little of the development of what we vaguely call the "scientific method and attitude." In addition, of course, teaching principles as if they were facts can hardly result in real understandings leading to applications in daily life.

Let us be frank, say the critics of the conventional program. The majority of the learning experiences the teacher provides in his race over facts are memoriter and verbalistic learnings. They do not habituate young people to critical attack on problem situations or to inductive reasoning, nor does the teacher guide the students toward a higher synthesis of critical abilities than they had when they came to the classes.

Nor can the laboratories be said to emphasize the development of scientific attitudes or critical abilities, according to the critics. A student is sent to the laboratory to find, with inadequate instruments, answers that he knows in advance or that he knows are in the teacher's notebook. The student does not determine the coefficient of expansion of a piece of metal by recourse to nature. On the contrary, he goes to the laboratory to see how closely he can get nature

to conform to the "right" answer that is somewhere in an answer book. The answer is, for the student, an arbitrary and authoritarian answer. Thus, laboratories are places where students often engage in the rather dubious game of checking as closely as they can against the (to them) arbitrary and unchallengeable authority of SCIENCE.

The critics remind us that most chemistry teachers sooner or later mix the chemicals so that students cannot get the results their laboratory manuals indicate that they should get. The manual may, for example, indicate that the cookbook procedure recommended will result in a white precipitate or a violet ring. The substitution of chemicals by the teacher makes the expected result impossible of achievement. Yet, the majority of the class will report the result that the manual has led them to expect. Is this obvious intellectual dishonesty a reflection on the personal integrity of the student? Not if we are to believe the critics. The teacher has taught the student that his task is to follow a step-one, step-two procedure. If the student does not get the expected result it is because his own inadequacies have not permitted him to achieve the "right" answer. The science teacher has actually taught this intellectual dishonesty and disregard for observable facts as surely as if it were one of the chief objectives of his teaching. So say the critics.

This, if the critics are right, is teaching authoritarianism with a vengeance. The teacher of the newer sort of science program admits to an impression that a good deal of conventional science teaching encourages the assumption that science is the "correct" dogma and that the scientist is the high priest of the modern mystery called SCIENCE. Let us admit, say the critics, that the conventional laboratories are really not laboratories at all. Our "experiments" are not experiments. They are visual-education devices whereby young people may visualize phenomena and gain facility in the manipulation of certain materials and apparatus. There is no objection to the use of laboratories for visual education. The objection is that we fool ourselves and delude our students about the meaning of what goes on in the high school laboratory. The objection is, further, that this use is not enough—that the laboratory should do more for the student, that the laboratory can, and should, serve the objective of developing critical procedures of thinking and inquiry.

The evaluation program shows where the emphasis lies in the conventional programs, say many of the critics. The student is evaluated chiefly on his ability to fill in blanks or to check alternative items which are designed to show what he has remembered rather than how well he can think. Instead of being required to apply his knowledge of facts and principles to the analysis and solution of problems, the student is asked to show what he can recall and identify.

Basic Elements of the Newer Programs

In the newer programs, the students assume a high degree of responsibility for planning the areas of content, the organization, and the procedures of the course. In more conventional programs, the teachers and textbooks largely

Are high school students sufficiently mature for effective independent work and cooperative analysis? Teachers of the newer programs think so and provide experiences designed to teach students to handle their own problems without teachers and textbooks at their side. (Official Photograph, Board of Education, City of New York)

determine these things. In the newer programs, the students are closer to the active center of the learning process than they are in conventional programs. The teacher counsels and stimulates the students and serves as a resource for guidance and technical information when other resources fail. Direct teaching is done, of course, but it is less prominent than in conventional programs.

These differences are not accidental. They are planned to achieve what is doubtless the most fundamental objective of the newer programs: developing in each student self-direction, purposiveness, and power of independent attack on problems. The analyst could use the term "scientific abilities" to identify these traits. The teachers of the newer programs more cautiously speak of "critical abilities." They attempt to provide experiences that will teach the student to handle his own problems without a teacher or textbook beside him. *The hope is to make the teacher and formal education increasingly dispensable.*

The teachers of the newer programs would probably accept the following list of competencies and traits as defining what they have in mind when they speak of critical abilities.

1. The ability to locate and define problems in the matrix of

confused patterns in which they are commonly found in real-life situations.
2. The ability to outline problems so that they may be analyzed and attacked by a logical sequence of steps.
3. The ability to secure relevant information from appropriate references and to distinguish between data that are valid and those that are invalid. This includes recognition of the basis of authority in any field and the meaning of authority in science.
4. An increasingly explicit understanding of science as a method of formal inquiry, with recognition of both its potential usefulness and its limitations when applied to socio-economic affairs.
5. Recognition of the validity of group as well as individual attack on problems and recognition of the common requirements of freedom for the advance of both democracy and science.
6. Increased ability in the communication arts—reading with perception and understanding, critical listening, effective speaking and writing, and effective participation in group discussion.
7. A tendency to act in accordance with available facts and within the value systems of both democracy and science.

The discerning reader will detect that the usually stated elements of "the scientific method" are imbedded in the list and that the list includes a good deal not commonly thought of as elements of that method.

What do these objectives mean in terms of procedure? What does a class typically do when the teacher has these objectives in mind? Each objective will be referred to in answering these questions.

Objective 1 suggests that neat problems, pulled out of their context of real-life involvement, will not suffice for effective education. Only in textbooks are problems neatly defined. In life, real issues and problems are submerged in a matrix of irrelevancies and false issues. This objective suggests that a primary responsibility of the science teacher is to assist young people to look more critically at science situations as they are found in life and to help them to locate and define the specific problems that are found in such situations.

The teacher of the newer programs usually avoids presenting clear-cut problems to the class. Rather, he helps the students to become aware of meaningful problem situations in science and helps them to identify and clarify the concrete problems involved in these situations. The problem situations chosen depend, of course, upon the maturity and interest of the group. In fact, they typically emerge *from* the group.

Objective 2 suggests group planning and deliberation. Commonly, the entire group plans the procedures to be followed in the attack on a problem and then

delegates to small groups or individuals responsibilities for investigation. At times, however, an individual student may have an interest not shared by the group at large. That student generally presents his interest or states his problem before the entire group. The group—or committees of the group—criticizes the structure of the problem and assists the individual student in refining it to the point where he understands clearly what things he must do in order to secure the data he needs to answer his problem or resolve the issue of his concern.

Objective 3 raises serious questions concerning the role of the textbook in the newer science programs. It must be recognized that the use of a single textbook with little or no attention given to other reference sources would prohibit the development of this objective, for the student who is never given the opportunity to check facts or to compare judgments and opinions of different authors will not be able to develop critical reading abilities to any significant degree. Moreover, the teachers of the newer programs insist that the student who goes through an all-too-typical high school program using but a single book in each course will emerge from high school no more able than when he began his high school work to use newspapers, periodicals, reference books, and technical bulletins critically when he needs information or wants to find various authoritative views on a subject or issue.

This does not mean that the teachers of the newer programs believe that textbooks are by nature bad. Some do. But most believe the question is how they are to be used. In many of the newer programs, no single textbook is used. Multiple sets of textbooks are available, as are other reference materials. However, in many of the newer programs a single basic textbook is placed in the hands of each student just as in more conventional programs. This textbook serves as a basic orientation point for the class. To the textbook is added a rich resource of library reference materials. The textbook serves as a lodestar for the group, as a group, and a reference point for learning expeditions into a wide variety of experiences and for the use of other reference materials. But the textbook does not dictate the coverage of the course.

The wide use of reference materials is held desirable not only for the reasons stated and implied in the objective being considered but also for two basic psychological reasons. First, the level of reading ability varies tremendously in most classes. In 1953, a ninth-grade general-science course with which the author did some work enrolled students whose reading abilities ranged from fifth grade to college senior and whose I.Q.'s ranged from 82 to 186. Any class may present a considerable range in student ability.

It is evident that a single reference and a single speed of coverage could be stifling to the student with high reading ability and I.Q. or frustrating to the student with low reading ability and I.Q. Both the student with low academic ability and the student with high academic ability would profit from disciplined consideration of many problems that they both must face. Furthermore, they

An adequate library is a *must* in the newer programs. If possible, it should be housed in the science room, as it is in this multipurpose science room which includes library, laboratory, construction tools, equipment, demonstration table, and movable tables and chairs in one room. (Courtesy College of Education, University of Illinois)

would profit by considering these problems together in the larger group. But one can penetrate far more deeply and range more widely than can the other. If each is to gain optimum development of his potentiality for self-direction and understanding, a wide variety of reference materials must be made available.

Second, a single reference—usually logically rather than psychologically organized—may be interesting and understandable to one student but not to another of equal reading ability and intelligence. There is a real distinction between psychological organization and logical organization. Unfortunately, science textbooks by their very nature, although sound in logical organization, may have little or no psychological organization so far as an individual learner is concerned.

Some of the newer textbooks are far better organized than the traditional ones in terms of student interest, readability, and "psychological logic." It must be emphasized, however, that the most gifted and insightful author cannot know and meet the various local situations that the teacher faces, nor can he provide an organization of content that will meet the particular psychological requirements of a particular student in a particular class. For this reason, the

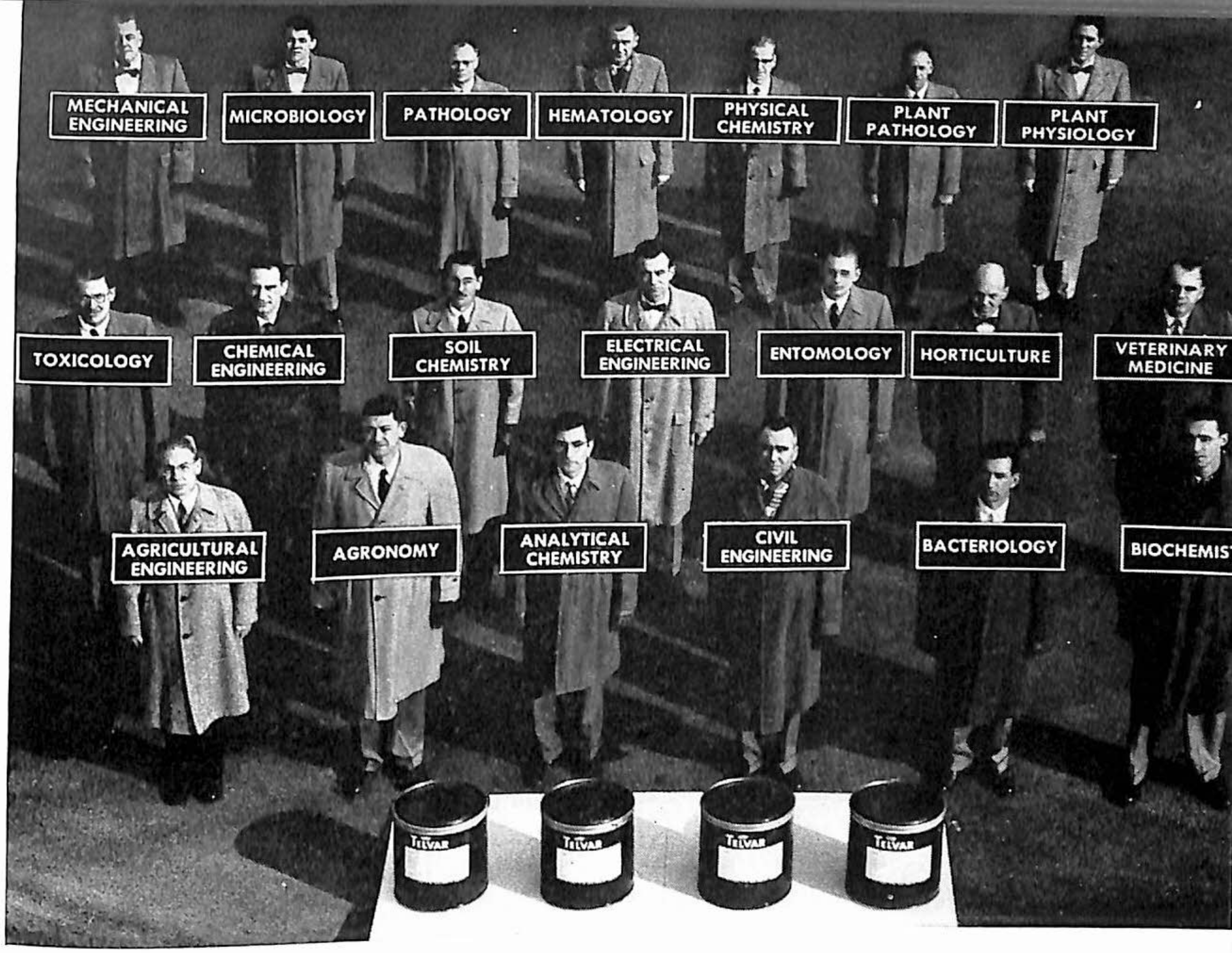
authors of some of the newer and better textbooks provide many suggested activities, reading materials, and sources that encourage the student and the teacher to go beyond the text into the life of the community and into a variety of reference materials. Here we have the rather odd, but to be encouraged, situation of a textbook itself weaning the student away from preoccupation with a single textbook.

A good example of this is a biology textbook that has been widely used in the newer science programs. The textbook and its accompanying workbook include a major unit in soil conservation. Approximately half the answers to conservation questions raised in the workbook cannot be answered or keyed by the authors, for the answers depend upon what is found in the local community and in reference materials available only from local organizations or pertinent only to the local situation. Such textbooks are frankly designed for teachers who want to teach the newer sort of science courses here being defined and who feel the need for the security a textbook affords.

Objective 4 suggests that students should recognize science as one of several historical and contemporary means of formal inquiry. The students' real understanding of science as a method will depend upon the adequacy with which the other six objectives are realized, for real understanding of a method is heavily dependent upon habituation in that method. Teachers of the newer programs tend to agree that the objectives here posited (including the value concept) are attributes of the critical procedure that, in formal fields of science, we think of as the scientific method. Objective 4 goes further than habituation, however. It suggests that it is valuable for students to take stock of formal procedures of investigation and to distinguish explicitly scientific inquiries from those of intuition, pure reason, revealed truth, philosophical and historical methodologies, artistic analysis and synthesis, and so forth.

In many of the newer programs, this is done in part by a study of significant periods in the history of science. Students are brought to discover certain common patterns in the general procedures and methods employed by men of science. But, unless students see the operation of science in its interaction with the many social forces of a particular time and place, their view of common patterns will be distorted. The work of Vesalius or Copernicus cannot properly or profitably be seen without the perspective provided by some understanding of the social forces operating in the sixteenth century.

Most of the teachers of the newer programs recognize the weakness of the conception of scientific method held by those who believe that we can find speedy answers to vexing social problems by rigorous application of the scientific method. They assist young people to recognize the difficulties of applying the methods of the physics laboratory to fields where uncontrollable variables make controlled investigation impossible. On the other hand, the very fact that the newer programs so often lose the fine distinctions between the natural and the social sciences (the dividing lines are inevitably lost or dimmed as real



No scientist really works alone. Cooperation and group verification are the ultimate keys to tested knowledge. This picture illustrates the specialized branches of scientific knowledge and research that were involved in the production of a single modern chemical. The newer programs accept the validity of group attack and verification. (Courtesy of E. I. DuPont de Nemours and Co.)

problems are attacked) is evidence of the interest of the teachers of these programs in helping young people to see that natural phenomena, including social phenomena, are amenable to scientific attack.

A dominant characteristic of the traditional classroom is competitiveness. The emphasis is on individual acquisition of information, and the work of individual students is evaluated by instruments permitting the placing of students in a rank order and on a distribution curve. A dominant characteristic of the newer programs is cooperativeness. Objective 5 implies this emphasis. The goal is the optimum development of each individual, and the procedures are generally those of shared and group responsibilities. This is believed to be the best sort of habituation in the democratic process and of significant help toward increasing the emotional maturity of the student. Furthermore, it is believed to be a good exemplification of the scientific process in modern times. Each scientist has stood upon the shoulders of those who have worked before him. Moreover, no scientist really works alone. He may carry on his investigations privately,

and he usually does. But they are fully reported in terms of assumptions and procedural details, as well as conclusions, so that any other investigator competent in the field can repeat the procedures to determine the validity of the conclusions reached. Conclusions in science are not acceptable until there has been considerable group verification.

In the newer programs, the student experiences the validity of this group attack. His assumptions, facts, and experimental procedures are exposed to the critical view of the group. He finds that sounder answers from any experiment are more likely to come from group analysis and synthesis than from his own single and uncriticized results.

All may share in the formation of assumptions and the collection of data as well as in the formation of tenable conclusions and generalizations. The individual student gains respect for group processes and presumably may learn that an argument or issue is best resolved by exposition of the facts and by both individual and group analysis rather than by the violence or repetition with which an individual conclusion or point of view is proclaimed.

The most common outlet for information, understanding, and attitudes in modern society is through verbal communication. The advancement of science, the maintenance and strengthening of democracy, and the solving of individual and common problems depend to a large degree upon the ability of the people at large to utilize the means of communication for their own understanding, for the persuasion of others, and for intelligent use of the ballot. Information and misinformation come like an avalanche to us through the press, movies, radio, and television. The intent is variously to educate us, to persuade us, to delude us; to induce us to buy this product, vote this platform, do this or that. Science is often prostituted in the process.

A chief goal of the newer programs is stated in Objective 6 of our list. There is no area of human experience that is not directly or indirectly affected by science. This objective proposes, therefore, that the student be assisted toward critical understanding of the written and spoken word and aided in developing his own ability to communicate his beliefs and views with cogency. Considerable time, in the newer programs, is taken by group discussions, panel discussions, library research, individual presentation, and informal group analysis. The intimate relation between language and thought is beyond dispute. Practice in clear written and oral expression is practice in clear thinking. The science teacher who feels that there is little profit in teaching science if the student does not make at least verbal use of it is impelled to provide considerable opportunity for each student to improve in such use through supervision.

Objective 7 does not need much elaboration. Presumably, we teach in order that our learners' actions may be socially more desirable and individually more satisfying. Too seldom have we helped students bridge the gap between knowledge and understanding on one side and action on the other. This gap has most commonly been noted in the area of health. What one knows about require-

ments for good health does not indicate what one will do. What one knows about the genetic and anthropological evidence of innate racial equality does not indicate what one will do on a racial issue.

Recall the old farmer who, when asked if he planned to attend a meeting on good farming practices, responded, "Heck no, I ain't farming now as good as I know how." Objective 7 implies the desirability of providing outlets for knowledge and attitudes so that young people will experience the satisfactions of successful action and will become habituated to taking action when it is both possible and desirable. Such experiences are required for the fullest development of intellectual maturity for young citizens of a democracy.

Action for high school students is often restricted by their youth and many other factors. Nonetheless, the teachers of the newer programs have usually discovered many avenues of action open to their students. Almost all these are communication actions such as writing letters to the editor of the local newspaper or addressing a service club on a local problem. But there are other forms of action, such as modifying relations with individuals of other races and religions, undertaking surveys of health, housing adequacy, recreational potentialities, wiser purchasing techniques and habits, sounder use of equipment, and so forth. These are forms of action. Teachers of newer programs do not leave these actions to chance. They help young people gain increased skill in these and other forms of desirable action.

PRACTICES DESIGNED TO DEVELOP FUNCTIONING UNDERSTANDINGS

Today's schools are properly charged with the responsibility of meeting the needs of all the youth that attend them. But the curricula of our schools have long been under attack as being poorly adapted to meeting the needs of many of the youth of school age, particularly the needs of the gifted. The Regents' study in New York State[3] and the Maryland study[4] were prototypes of studies that have been made—and continue to be made—in many states of the Union in an effort to discover how well the schools are meeting the needs of youth today.

The results of these studies have been discouragingly consistent. They have shown that the conventional American high school program contributes chiefly to preparing a limited number of students to enter college (not necessarily to their success in college) and but little to understandings and skills that will

[3] Ruth Eckert, and Thomas O. Marshall, *When Youth Leave School* (New York: McGraw-Hill Book Company, Inc., 1938); F. T. Spaulding, *High School and Life* (New York: McGraw-Hill Book Company, Inc., 1938).

[4] Howard Bell, *Youth Tell Their Story* (Report of the Survey of Youth in Maryland by the American Youth Commission; Washington: American Council on Education, 1938).

develop an informed individual or help him toward personal happiness and security and toward competent citizenship. More recently, a general awareness has developed among teachers and laymen alike that the above-average students—the gifted—are badly neglected in many of our schools.

Criticisms of the Older Programs

The fields of science instruction have not escaped these criticisms. How do the proponents of the newer programs see the content of the conventional science courses?

They insist that serious analyses of many conventional general-science or biology courses makes clear that the content is superficial and that there is too much about science and not enough science. They state further that analysis of a typical high school chemistry or physics course leads, inevitably, to the conclusion that most of the student's time is taken up by routine, logically organized activities poorly related to significant problems and poorly designed to motivate students to thoughtful and sustained intellectual work. Such activities, according to the critics, tend to prolong immaturity rather than to foster maturity.

The average science teacher will probably object to the foregoing criticisms. He will doubtless insist that conventional physics and chemistry courses provide the student with an understanding of his physical environment that should equip him for far greater enjoyment of his life and provide insights and skills that will enable him to live more competently, safely, and securely. Many conventional courses undoubtedly do just that. But the critics say that if these values do emerge it is because of dynamic teachers and despite the organization and general pattern of such courses.

Stanley and his colleagues gave what is, perhaps, the most cogent expression of the general criticism that the proponents of the newer programs have made of the logically organized science subjects.[5]

> The fact is that the "organized subject matter" of the sciences represents the end product of learning rather than the process by which learning takes place. It is true that in the hands of the mature scholar this "subject matter" is an effective tool of further research. But that is precisely because he is a mature scholar; for the immature beginner it is, typically, a set of verbal formulae having little or no relation to his experience and interests. . . .
>
> In the second place, it does not follow that the order and sequence appropriate to the problems of the research specialist is necessarily identical with the order and sequence appropriate to the citizen.
>
> The organizational pattern adopted by the research disciplines

[5] William O. Stanley and others, *Social Aspects of Education* (Champaign, Ill.: Stipes Publishing Company, 1948), pp. 136–137.

was designed for a definite and highly specialized purpose. The scholar's problem is primarily intellectual, the discovery and verification of further knowledge. . . .

The problems of the man and the citizen, on the other hand, are practical problems. As such they are primarily concerned, not with the discovery of knowledge, but with the making of decisions and the formulation of policy.

The difference, therefore, is that between the organization of material appropriate to the development of a systematic body of theoretical knowledge and the organization of material appropriate to the application of knowledge to the control of some practical human enterprise.

The advocates of a curriculum composed of elementary and condensed reproductions of the contents of the various research disciplines ignore these fundamental distinctions between the problems of the scholar and the problems of the man and the citizen. Consequently, they have confused general education with an additive summation of elementary courses selected from professional education programs in the various scholarly disciplines. And they have also confused verbal mastery of propositions embodying information with functional and meaningful knowledge.

Basic Elements of the Newer Programs

There is no set body of content that can be said to reflect the newer programs of science. In one way this is unfortunate, because it is impossible to describe generically the content of one of the newer programs. What it is this semester may be considerably different in its details from what it will be next semester. The reason for this is that the teachers of the newer programs give priority to the seven competence objectives that have already been explored. These objectives obviously prohibit a teacher-dictated static content and encourage flexibility and group consensus on appropriate content.

It is an error to assume, however, that the newer programs are shapeless and without direction or that they represent easy or superficial treatment of science content. Although the details of content cannot be stated, each student in a newer course tends to penetrate more deeply into several aspects of the science being studied than he would have in the older programs. Coverage of content is generally not so broad in the newer programs as in the older ones (although individual gifted students may cover even more material). But the content emphases in the newer programs are in depth rather than in extensiveness. Each student is expected to know well what he knows. Mastery, subject, of course, to the individual student's ability, is the content goal.

In addition, there are three criteria which aid in the selection of appropriate content for general education purposes. All students are expected to know

certain principles and facts of importance in personal and social affairs. The first criterion is the problems and needs of the students themselves. Space prohibits cataloguing them at this point. But anyone who has studied the many reports and investigations on the needs of youth[6] is aware of the fact that students have some basic needs pretty much in common. The help that a particular student will require in meeting a need will be different from that required by another student, perhaps, but he will have needs in common with others. The "Imperative Needs of Youth" posited by the Educational Policies Commission of the National Education Association[7] is one form in which these research data have been summarized for curriculum use.

The teacher of the newer program conceives it to be his responsibility to contribute from his field of expertness that which is of clear value to the students in meeting their needs. One should not assume, however, that science teachers in good newer programs convert their courses into easy-going superficial discussion centers of boy-girl relations or fly casting. The need must be significant, and the contribution of the science genuine, before good teachers will devote instructional time to it.

Societal needs serve as another criterion for the selection of content in the newer science courses. For example, many teachers have undertaken to help young people to gain a clearer understanding of our scientific and technical ability to provide for human wants in production, health, conservation, and so forth. The goal is to provide understanding of the technically possible and the gap between this potentially possible and the present actuality in order that students may have a firmer basis in facts upon which to judge the many proposals being put to the American people to narrow these gaps.

There are many areas of social concern in which the science teacher of the newer programs assumes responsibility. Modern mass production; the interrelations of peoples and nations in the modern world; naïve, undemocratic, and antiscientific conceptions of superiority of one racial group over another; the control of atomic energy and its directed development for the benefit of mankind; the larger questions of world unity and peace—these are typical of the areas considered in many general education (as against specialized) science courses.

The value system of democracy forms the third criterion in the newer programs. Chapter 1 and some parts of this chapter have considered this and the contributions science can make to it.

Admittedly, these criteria imply a rather different conception of the responsibility of the science teacher than that traditionally held. But the teachers of the

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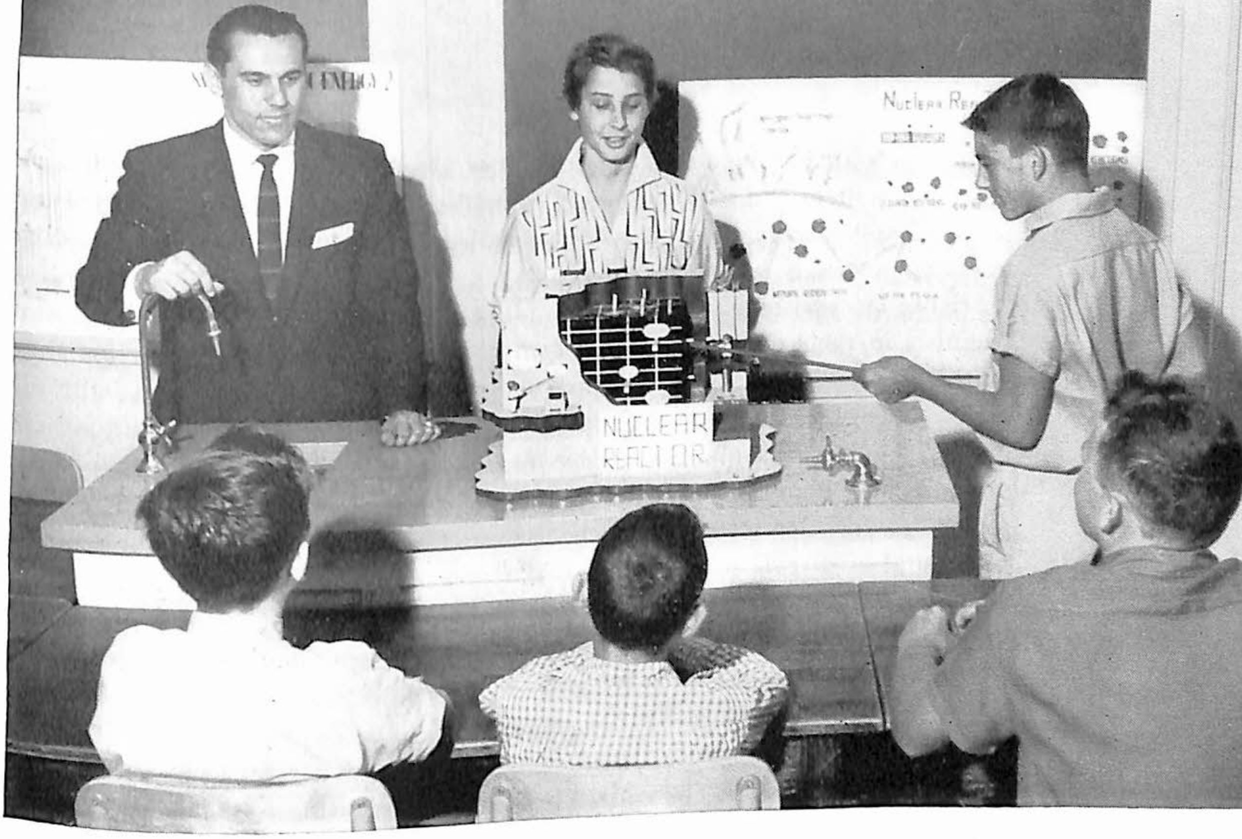
[6] See, for example, Donald C. Doane, *The Needs of Youth* (Contributions to Education No. 848; New York: Bureau of Publications, Teachers College, Columbia University, 1942).

[7] Educational Policies Commission, *Education for All American Youth* (Washington: National Education Association, 1944).



Many science teachers now deal with problems affecting society as a whole, in which scientific knowledge forms a prerequisite for informed social policy. Will these students be more effective citizens as a consequence of their study of the development and control of atomic energy? (Courtesy of Los Angeles Public Schools)

newer programs will insist that no one else in the school is as well equipped as the science teacher to make certain significant contributions to the preparation of young people for satisfying living and effective citizenship. They insist, too, that, although the newer programs are at least as rigorous as the traditional programs, students learn better because their interest is higher and the demand on them is for more reflective work. If this judgment is sound, the newer programs may also have achieved one of the highest goals of a good teacher in any field—to leave the student at the end of a course more interested in the area than he was when he entered the course. If the newer programs have done nothing more than this, if they have inspired and stimulated the student to want to continue his work with the philosophy, methods, and body of tested data we call "science," there is much to be learned from them. Such courses are often considered as "feeder" courses into specialized courses in physics, chemistry, and biology.

SUMMARY

It is impossible to teach effectively unless one is clear about what his teaching is to accomplish. Clarification of purposes must precede analysis of methods,

for methods are a function of the goals they are designed to achieve. Selection of science content and its organization into effective learning activities for young people imply clearly seen goals and an awareness of how each step in the learning process is related to the goals.

Science teachers have a dual responsibility. They must challenge the potential scientists in their classes and help them toward professional careers. But they must also provide the soundest possible general education in science for all their students regardless of their abilities. To inspire and help either of these groups requires a sound knowledge of the science taught. This knowledge must be more than enough for teaching routinely from a textbook. The teacher must know his science well to breathe life into his subject. A thorough knowledge of natural science is necessary, also, if the teacher is to plan his teaching in terms of the needs of his students. With a good background in science, the teacher is in a position to determine what his science has to offer to young people. He can study alternative goals and procedures and make wise choices if he knows his science well.

But thorough command of natural science, though essential, is not enough to produce a master teacher. Many well-trained scientists have learned this to their chagrin. Teaching is a complex art and a science. Human beings are complex, and the teacher must be skilled in resolving the problems he will meet in working with groups of young people. He must understand the learning process and how to organize and teach his science so that his students will be challenged, inspired, and eager to learn. He must learn from research and the experience of good teachers so that his students will be given the best instruction that such research and experience make possible.

Two types of science teaching exist in American schools today. Good teaching can be found in both types. But each teacher should carefully consider which type of teaching is better suited to the goals of intellectual, emotional, and ethical maturity. Examination of the older type of teaching has given rise to severe criticisms in terms of these goals. Out of these criticisms has evolved the newer type of science teaching. The older method is best described as an attempt to cover a logical organization of a science primarily through the medium of a textbook. Related activities, such as laboratory and field work, are designed to help clarify the facts and concepts developed by the text. The teacher's chief responsibility in such programs is to make the science, as developed by the textbook, as real and meaningful as possible to the students.

The older programs have created certain problems and raised some important questions. Critics have said that such programs have done little to develop critical and reflective thinking. The laboratory work in such programs is really visual education and does not promote thought or inquiry. The attempt to cover the material presented in the book results in a swift pace that permits little time for reflective activities and results in superficial, verbalistic learnings for most students. "Problems" in such programs are textbook problems that are

completely alien to the types of real-life problems that can be solved through scientific techniques and knowledge. Such courses are therefore considered by many as boring, stultifying, and incapable of helping young people equip themselves either for out-of-school life or for the rigorous work expected of them in colleges. Good students develop habits of laziness and an attitude of getting by.

The newer programs place the student closer to the center of the learning process. Students have a higher degree of responsibility for planning, making choices, and investigating. The teacher's role is more like that of a major professor in a research seminar at the graduate-school level. He challenges, stimulates, guides, probes, directs, interprets, and even goads his students. But he does so in terms of the fundamental purpose of such programs: to develop purposiveness, self-direction, and disciplined powers of thought in science among his students. His teaching procedures are designed largely to develop critical and thoughtful abilities in his students. (Seven competencies were identified and discussed in terms of procedures in this chapter. These represent one categorization of goals and related procedures common to the newer programs.)

The content of the newer programs cannot be precisely stated. Unlike the older programs, in which the textbook clearly reveals what is studied, the newer programs, which place a premium on developing the student's power of study and thought, make no attempt at covering a particular body of content. Rather, considerable flexibility is provided. But students are expected to learn well what they learn. The theory behind this is that a student who penetrates rather deeply and thoughtfully into several fundamental areas of science develops greater maturity and is better equipped to continue his study of the science after he leaves teachers and textbooks than one who learns more broadly but superficially and with little reflection or opportunity to use a variety of references and laboratory materials. Mastery, then, not coverage, is the content goal. But the newer programs also reflect the viewpoint that every American youth should have a general knowledge of at least a number of areas of science that are important in personal life and for citizenship activities. Rather than suggesting possible details of content areas, the preceding material stated three criteria that teachers often use in searching the archives of science for contributions to the education of youth through courses frankly designed for general education (as against specialized) purposes. These criteria are

1. The significant needs of youth to which science can make a real contribution
2. Important societal needs to which science can contribute effectively
3. The values of freedom-loving people, which have emerged from the struggles of mankind toward dignity, freedom, and justice

Science, like democracy, requires freedom of the mind for its survival and advance. Therefore, many science teachers feel that teaching some aspects of the philosophy and history of science to their students is one way in which they can give support to the values of science and democracy alike. Additionally, most science teachers in the newer programs are convinced that practice in democratic and intellectual activities in the classroom is the soundest possible means whereby young people will grow in skill in, and respect for, the method of uncoerced intelligence as applied to both scientific advance and a democratic society. This, they feel, is the surest road to the development of maturity in their students.

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FOUNDATIONS OF MODERN SCIENCE TEACHING

II

3

THE HISTORICAL BASIS OF CONVENTIONAL PRACTICES

The history of the American school system and its borrowings from Europe is not a study of dead issues. Nor should it be of interest only to antiquarians, for the roots of our present practice lie in the past. Unless one can examine modern practices with some recognition of the historical conditions that created them he may deal myopically with professional problems that require clarity of vision.

We who teach science are accustomed to certain practices and may think of them not only as natural and proper but as the only conceivable means whereby sound education of the young can be secured. We may search for better means of selecting textbooks for instruction without thinking to raise the more fundamental question of the proper role of the textbook or whether, after all, the most fruitful learnings come from the use of a basic textbook. We may search for better ways of motivating our students and maintaining sound discipline without questioning our entire classroom and administrative setup, some parts of which may reflect the days of the Latin grammar school, puritanical conceptions of the native sinfulness of the child, and hickory-stick conceptions of discipline.

Much that is good has been inherited from the past. But some useless and harmful practices that originated in the past still persist. Some of these repre-

sent psychological theories that are untenable today. Some were originally designed to meet needs that no longer exist. If we are to master the art of good science teaching, we must explore the bases of present practice in assumptions, values, beliefs, needs, and goals. And we must recognize the strong hold of the past on the present so that we can eradicate those practices that are still maintained out of mere inertia while we hold on to and support those practices that have proved of present worth. This chapter undertakes a brief résumé of the forces and circumstances that have been of particular influence in the development and growth of science instruction in America.

THE AUTHORITARIAN NATURE OF THE FIRST SECONDARY SCHOOLS IN AMERICA

The first secondary school established in America was the Boston Public Latin School. It was established in 1635 to prepare students for admission to Harvard College. Harvard College, in turn, was concerned almost exclusively with the preparation of ministers of such orthodoxy as to perpetuate the religious and moral concepts of the theocratic leaders of early Colonial times.

What was expected of the students enrolled in the Boston Latin School is indicated in the entrance requirements of Harvard College at the time.

> When any schollar is able to read Tully, or such like classical Latin author ex tempore, and make and speake true Latine in Verse and Prose, *suo ut aiunt Marte;* and decline perfectly the Paradigms of Nounes and Verbes in ye Greek tongue; then may hee bee admitted into ye College, nor shall any claime admission before such qualifications.

The Latin grammar school was imported from England practically lock, stock, and barrel. Investigations of the Boston Latin School disclose that its curriculum, in the late 1700's was almost identical with that found in Winchester, England, about 1600. Not only was the program borrowed from England, it was borrowed from England's past. And it was not long before the pattern of the Boston Latin School curriculum was adopted in many towns throughout New England.

These schools enrolled a selected group of students, and their classical and linguistic program of studies was unsullied by such "practical" fields as science. The student was made to read selections from Caesar, Virgil, Homer, and Horace and to study the niceties of translations and Latin and Greek grammar. These matters, coupled with a study of the scriptures, constituted the program of the schools.

One should not assume that the small and highly selected student population represented an aristocratic notion of the early colonists. Obviously, the purposes and the curriculums of the schools were not designed for the mass consumption of the "average" Colonial child. But there had been no secondary schools

prior to the establishment of the Latin grammar schools, and these schools were founded to meet a very definite need that was considered urgent at that time. This was the need for training an orthodox ministry that would maintain the faith. Harvard College was established to do this job but depended upon a supply of promising students. It was the function of the Latin grammar schools to perform the task of preparing these students. Thus the Latin grammar school met a real (or at least a presumed) need of the time.

It is probable that a curriculum of high utilitarian worth in terms of the broader needs of the Colonial culture would have attracted few students. For the fact is that most of the colonists were poor and they were busy subduing a frontier wilderness. They needed the labor of their children to assist in making a living.

It is nonetheless a fact that the curriculum of the first secondary schools of America not only excluded science *but was distinctly antiscientific, from a philosophical point of view.* This is to say that authoritarian techniques were employed and the purpose was to indoctrinate the young. This despite the fact that the brief history of the Latin grammar school was contemporary with a vast and increasing popularization of antiauthoritarian experimentalism, particularly in Europe. The curriculum grew indigenously from the Puritan belief that man's chief purpose is the glorification of God and preparation for life after death. It is not surprising, then, to find that the educational theories and methods of instruction of the time were heavily influenced by the Puritan conceptions of human nature and the requirements of "mortifying the flesh" to advance the spirit's cause.

Children were held to be depraved by nature and to require strict and rigorous discipline for the development of obedient piety. The child's sinful will had to be broken, and he was required to develop an unquestioning obedience to adult authority. The more difficult, tedious, and hateful the study, the more the disciplinary value and the higher the mental faculty developed.

The classics, which comprised the curriculum, were not commonly taught for their mind-freeing and liberalizing value nor for their beauty and power as expressions of the human spirit and intelligence. They were taught through long hours spent in word memorization, translations, and grammatical and linguistic exercises of exactitude, so that discipline and the subjugation of the personal will to authority might be developed. The very irrelevance of the subject matter to the Colonial culture and the practical affairs of man contributed to their high "disciplinary" virtue, for this increased the rigor of the learning process. The hickory rod was liberally used, as is commonly known, to help the process of subjugation and attendance to studies. Little nonsense was allowed; and, should the will of the student to work at his studies flag, or the eye wander to the real world outside the schoolhouse window, corporal punishment was soon applied.

It should not be thought that the Puritan theory of life was obscurantist.

On the contrary, the belief that despotism in politics and popery in religion could best be combated through a literate people, capable at least of reading the Bible, caused the Puritans to develop the system of popular elementary education in New England—almost completely novel in the world at the time—and to support it through attendance laws and taxation. But the higher schools carried out a different function entirely. Whether or not they did a sound job of preparing youth for college is somewhat beside the point. The Harvard College requirement for entrance was clear, and the Latin grammar schools were designed to meet the need.

CRITICISMS OF THE LATIN GRAMMAR SCHOOLS

There were criticisms of the Latin grammar schools almost from their beginning. In Pennsylvania, William Penn declared for an education that would give his own children needed mathematics and skills useful in carpentry, surveying, navigation, and agriculture. He asked for an educational program that would make good house wives of his daughters and that would develop honest, healthy, and industrious citizens for the young nation.

It was not a single cry. As America moved to and through its political revolt from its mother country, criticisms of the Latin grammar schools rose from all walks of life. Increasing numbers of people recognized the stake of the young country in an informed citizenry who knew their social institutions, knew the historical backgrounds upon which they could build, and who could work together to move society forward.

The growing industries required men trained in the sciences. Sound training in agriculture was particularly asked for. This was Penn's chief request of education. And, in 1777, Patrick Henry declared before the Virginia Assembly, "Since the achievement of our independence, he is the greatest patriot who stops the most gullies." Practical subjects were called for that might produce men who could farm wisely and conserve the soil.

Others took note of the larger American scene and saw the implications for education if the country was to advance and take its rightful place among the nations of the world. They were becoming increasingly aware of the kind of education that would be required to sustain and advance the young republic. It was clear to many that some means had to be established to make the industrial, agricultural, and scientific revolutions a potent force for the advance of America. In 1840 and in 1855, Baron von Liebig, a German scientist, published two books on agricultural chemistry which showed how nitrogenous compounds, as well as natural manures, could fertilize soils. His books contained much information that might be applied to American farming. And these were but two of a growing number of books being produced by the revolution in scientific thinking and in technology in Europe. Some means were required to disseminate such information. A new education was required.

Increasingly, therefore, the Latin grammar schools were denounced for their antique curricula and their allegiance to an imported content from the past that was divorced from the larger needs of the time. But the schoolmen—typically young ministerial students—generally made no attempt to modify their programs or to bring in modern subjects. Few of the Latin grammar schools were capable of changing, so most of them died. A few, including the Boston Public Latin School, changed into outstanding modern preparatory schools. But most of them left no direct descendants, although they clearly influenced the academies that eventually took their place. And the schools of today bear their imprint.

BACKGROUND OF THE ACADEMY MOVEMENT

Just as the Latin grammar schools resisted the intrusion of more modern subjects into their curricula, so, in Europe, did the universities and schools generally resist the development of the natural sciences. The record is of importance for it illustrates the tremendous resistance to change that is common among those whose ignorance or whose vested interests in an educational program cause them to erect barriers to logic, evidence, and, therefore, to the possibilities of change and growth.

Early Advocates of Educational Reform

Montaigne (1533–1592) was one of those who attacked this inertia in Europe. He wrote of the distinctions between life and "bookish" school learning. In his essay *Of Pedantisme,* he stated,

> We are ever readie to ask, "Hath he any skill in the Greke or Latin tongue? Can he write well? Doth he write in prose or verse?" But whether he be growne better or wiser, which should be the chiefest of his drift, that is never spoken of; we should rather enquire who is better wise than who is more wise. We labour, toyle, and plod to fill the memorie, and leave both understanding and conscience emptie.

Francis Bacon, who was the great popularizer of the growing science of the day and a strong advocate of educational reform, held that the existing type of education both in the schools and universities of his time did little to advance learning. He pointed out that education was preoccupied with words rather than things. In his *Advancement of Learning* he argued,

> . . . for men began to hunt more after words than matter; and more after the choiceness of phrase, and the round and clean composition of the sentence, and the sweet falling of the clauses, and the varying and illustration of their works with tropes and figures, than after the weight of matter, worth of subject, soundness of argument, life of invention, or depth of judgment.

Nearly a century later another Englishman, John Locke, wrote, in his *Some Thoughts Concerning Education,*

> When I consider what ado is made about a little Latin and Greek, how many years are spent in it, and what a noise and business it makes to no purpose, I can hardly forbear thinking that the parents of children still live in fear of the schoolmaster's rod, which they look on as the only instrument of education; as a language or two to be its whole business.

And even Louis XIV, king of France and a contemporary of Locke, is quoted as saying,

> The systematic education of the youth in the colleges of the University leaves much to be desired; the pupils learn at most a little Latin but know nothing of history, geography, and most of the sciences necessary for daily intercourse.

Leibnitz, another contemporary of Locke and the mathematical genius who perfected differential equations and was co-inventor of the calculus, was so annoyed at the universities that he spent considerable time in promoting an academy to be devoted to the study of science, medicine, and other useful subjects. He criticized the Latin grammar schools with vehemence and held that the teaching of youth should be centered in gaining "living knowledge" through work in anatomical theaters, chemical laboratories, and botanical and zoological gardens.

The Scientific Revolution

Why all this ferment and fuss both in America and in the countries of western Europe? The humanistic tradition had degenerated into classicism, and scholarly work into scholasticism in the universities and schools of the Western world. This had been under way for some time and could hardly, by itself, have accounted for the wave of protest and demands for a more meaningful curriculum. Protest movements are common in the history of human endeavor, but a positive force is required to move the old—however outworn—off dead center. The force, in this instance, was the revolution in man's thinking created by the swift strides of science.

Science in the sixteenth, seventeenth and eighteenth centuries grew despite, rather than because of, the universities. It was, of course, a part of the general spiritual and intellectual rebirth known as the "Renaissance." The monumental works of Copernicus and Vesalius, both published in 1543, the work of Brahe, Galileo, and Kepler, of Harvey, Van Helmont, Newton, Boyle, and Torricelli, and the work of hundreds of lesser men and dozens more of the titans had created a growing awareness of, and interest in, natural philosophy and the various sciences among the literate people of Europe. A new and

fascinating world was available for the inspection of those who were interested. And many were interested.

Scientific societies and academies sprang up throughout Europe in about the middle of the seventeenth century. The universities typically opposed the new experimental sciences, and the experimenters of the time flocked together into organizations where they could share the results of their work. Galileo, who was censured rather than praised for his experimental demonstrations of how truth can be wrested from nature, and who found it expedient to leave his professiorial post and the city of Pisa, helped establish the *Accademia del Cimento* (Academy of Experiment) in about the middle of the seventeenth century. Perhaps the obscurantism of the schools and universities accelerated rather than stemmed the tide of free experimentation and search for truth.

The determined, yet condescending, mind-set of the men of the universities against experimental work, as well as the legitimate claim against the universities made by scientific workers and their growing numbers of friends, is clearly seen in a letter written by the provincial of a Jesuit province to a member of the order who claimed he had discovered sunspots in 1611. The Jesuit wrote,[1]

> I have read Aristotle's writing from end to end many times, and I can assure you I have nowhere found anything similar to what you describe. Go, my son, and tranquilize yourself; be assured that what you take for spots on the sun are the faults of your glasses, or of your eyes.

This dogmatism is matched by the following example of "pure reasoning" that scorned and actively opposed the experimental sciences from the vantage point of university authority. A professor of mathematics at Altdorf wrote,[2]

> When a body falls it moves faster the nearer it approaches the earth. The farther it falls the more power it possesses; for everything which is heavy hastens, according to the opinion of philosophers, towards its natural place, that is, the center of the earth, just as man returning to his fatherland becomes the more eager the nearer he comes, and therefore hastens so much the more. Still another natural cause contributes to this. The air which is parted by a falling body hastens together again behind the ball and drives it always the harder.

The fact that these viewpoints were wrong is beside the point. Such viewpoints continued to be held in major universities long after Galileo's demonstration of their fallaciousness. Error is not obscurantism. But refusal to look at demonstrated truth and to correct error is.

The record is clear that the demand for the inclusion of the descriptive and

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[1] Quoted in J. J. Fahie, *Galileo: His Life and Work* (London: John Murray, 1903), p. 103.

[2] W. T. Sedgwick and N. W. Tyler, *A Short History of Science* (New York: The Macmillan Company, 1917), p. 218.

the experimental sciences in the schools and universities of both Europe and America came from outside those institutions. And it was this demand that gave rise by the middle of the eighteenth century to the second form of secondary education that emerged in the United States—the academies. These were secondary schools for children and should not be confused with scientific academies. A similar movement had developed in Europe about a hundred years before in the form of clandestine "nonconformist academies," but our attention will be focused on the American pattern.

THE ACADEMY IN AMERICA

The academies were private institutions. Some were supported by companies which sold stock among the parents of the students. Others were established by individuals as profit-making enterprises. In many cases, an individual teacher established an academy just as the average medical doctor today hangs out his shingle and engages in private practice.

One of the earliest was the Philadelphia Academy for the Education of Youth, founded by Benjamin Franklin, who was quite vocal in his demands for practical education. This academy was established in 1751 and, although it soon degenerated into an institution quite similar to the Latin grammer schools, it represented an attempt at change.

By the middle of the nineteenth century, the academy movement was well established, and its curriculum, although exceedingly varied, was heavily "practical." In 1850, Massachusetts had over 400 such institutions; New York had well over 150; and Pennsylvania had about 150 chartered academies and probably as many more private and unchartered institutions of the same general character.

As tuition was charged by the academies, the students generally came from the upper socioeconomic classes of the population. Nonetheless, the base of the academy enrollment was considerably broader than that of the Latin grammar schools. In 1850, New York State had around 15,500 students enrolled. Furthermore, the academies enrolled girls as well as boys, a development unthought of in the days of the Latin grammar schools.

The academy movement did not develop a unified or common curriculum. Since the schools were established by local groups and since they were staffed by individuals of different abilities and backgrounds, the curricula they offered varied accordingly.

But the emphasis on usable and practical subjects was real and common. The strong nineteenth-century influence on American culture of the growing fields of science and technology made it inevitable that instruction in the natural sciences should find its way into the program of the schools of the time. Language arts, mathematics, and the natural sciences—these were the backbone of most of the academy curriculum. A study of the offerings in 167 New York State academies in 1853 has been made by Gifford. The courses of instruction offered in science,

as represented in contemporary Regents' reports, are shown in the accompanying table.

ACADEMY SCIENCE OFFERINGS IN 1853

Subject	*Number of Academies Offering*
Geography	162
Navigation	25
Astronomy	152
Civil engineering	12
Natural philosophy (physics)	161
Electricity	50
Hydrostatics	3
Magnetism	42
Technology	7
Optics	34
Mechanics	43
Chemistry	141
Agricultural chemistry	14
Anatomy	66
Hygiene	41
Botany	119
Natural history	35
Natural theology (support of religion through science)	22
Geology	56
Meteorology	17
Mineralogy	17

Source: Walter John Gifford, *Historical Development of the New York State High School System* (Albany, N.Y.: J. B. Lyon, 1922), p. 81.

The reader should understand that these "courses" were not designed, as are modern high school courses, to take up a set period of time each day for five days a week over the period of a semester or a year. Units of credit were unknown at that time, and no attempt was made to stretch or cut the course to fit the Procrustean bed of an arbitrary time schedule.

Nor was it possible for the teacher in Franklin's academy to lean on a textbook for support. There were no textbooks as we know them today. The teacher simply taught, as best he could, from whatever sources in which he could secure material, for as long as and in the fashion that seemed educationally profitable. The teaching of natural sciences in the early days of the academy was somewhat comparable to that in the elementary science program in the American schools today. Opportunistic, varied, unstructured, it yet had the great strength of being squarely directed, in many schools, to the direct or apparent local needs and the interests and concerns that appeared to be fore-

ELEMENTS

OF

CHEMISTRY,

IN WHICH THE

RECENT DISCOVERIES IN THE SCIENCE ARE INCLUDED

AND ITS

DOCTRINES FAMILIARLY EXPLAINED.

Illustrated by numerous Engravings,

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DESIGNED FOR THE USE OF SCHOOLS AND ACADEMIES.

BY J. L. COMSTOCK, M. D.

Mem. Con. M. S.; Hon. Mem. R. I. M. S.; Author of Notes to Conv. on Chemistry, Author of Gram. of Chemistry; Elem. Mineralogy; Natural History of Quadrupeds and Birds; Natural Philosophy, &c.

FORTY-NINTH EDITION.

NEW-YORK:
PUBLISHED BY PRATT, WOODFORD & CO.,
No. 63 WALL STREET.
1844.

Comstock's *Elements of Chemistry* was typical of the early chemistry texts. The photostat above is from the forty-ninth edition, published in 1844, which was widely used in the academies of the time.

most. There was no rush to cover a textbook or a particular syllabus deemed sacrosanct by some author or central authority. There was time to learn for those who could and would, simply because there was no general conception of what must be covered in a particular period of time. As new science content became available and the importance of a particular aspect became apparent, the teacher simply changed his emphasis. There were no college-entrance examinations that covered a science field and that could be studied by the academy teacher in order that he might prepare his students for college.

But textbooks were not long in coming. The New England primer, widely used in elementary schools during the eighteenth century, soon found its counterparts in such science texts as Gray's *Chemistry; Containing the Principles of the Science, Both Experimental and Theoretical,* which was published in 1852. The textbook method soon became *the* method.

Clearly, the early academy program of science—if, indeed, it could be called a program—had all the disadvantages that grow from lack of any standardization, adequate curriculum materials, concensus of objectives, and minimum standards of teacher preparation. Equally clearly, it represented a society that was on the march, that was virile, optimistic, ready to experiment, willing to shuck off subservience to the dictates of central authority, whether ecclesiastic, civil, or pedagogical. For every incompetent instructor who had no idea of what he was doing there must have been another teacher who, not having a dictate from a text or a commission, thought his way through to a sound and flexible program of instruction that, with minimum educational falderal, went directly at the job of educating young people for specific understandings, skills, and attitudes that reflected their personal needs and that of their society. The very informality of the early academy instruction may well have created a climate of group identification in the processes of learning that is equaled today in only a few schools—those that have had the courage to call a halt to the organized race over facts and reflectively and flexibly to study science as a dynamic force.

The emphasis upon utility was apparently not a narrow emphasis upon the development of specific skills, valuable in the market place, at the expense of insights and understandings. This may have been true of the language arts and of mathematics. But there is considerable evidence that, although the sciences did not neglect the immediately practical, there was primary concern for the development of critical thought processes, attitudes, and fundamental understandings.

Moreover, the academy, as distinguished from the Latin grammar schools, developed a wide range of activities that, today, would be held extracurricular. Such a distinction never occurred to those in the academies, for the curriculum was quite flexible, both in organization and in time spent on any particular subject or activity. Today's school may typically teach astronomy in the classroom while leaving to a science club the possibility of building a telescope and carrying on real exploratory and investigatory activities. Not so in the academy.

PREFACE.

The doctrine of definite proportions, being now universally adopted, forms one of the fundamental principles of chemical science. And whether the theory of atoms, which accounts for the facts on which this doctrine is founded, be true, or false, the doctrine itself will ever maintain its integrity, its elements being nothing more than the expression of facts which experiment and analysis have developed. The subject of proportions, independently of its relation to the theory or practice of Chemistry, is highly curious and of uncommon interest, both to the naturalist and the moral philosopher. To the first it shows that the laws of nature are equally inherent and efficient, in dead and in animated matter, and that the effects of these laws are as peculiar and distinctive in the formation of chemical compounds, as they are in the production and habitudes of the different races of animals. To the moralist, this subject teaches, that nothing has been formed by the fortuitous concurrence of atoms, but that even the "stocks and stones" bear the impress of creative agency and design—that the air he breathes and the water he drinks, are formed of invariable proportions of certain elements, and that these compounds are so precisely adapted to his nature and wants, that the least change in the proportion of their constituents would inevitably effect his destruction.

Besides the charms which this subject presents to the reflecting student, the composition of compound bodies, in recent books of chemistry, is expressed in equivalent numbers, and therefore cannot be understood without a knowledge of the doctrine of proportions. The author, therefore, before the description of each element and compound, has affixed to its name, at the head of the sections, its combining number, or atomic weight. By this arrangement, the pupil, at a single glance, becomes acquainted, not only with the scientific, and common names, but also with the composition, and proportions of all the compounds described.

In respect to the authorities which have been consulted in the composition of this work, the principal are Dr. Thomson, Dr. Henry, Sir H. Davy, Mr. Gray, Dr. Ure, Mr. Accum, Mr. Faraday, the Library of Useful Knowledge, the Journal of the Royal Institution, Silliman's Journal, and Dr. Turner.

Of the work of the latter author, free use has been made, his arrangement of subjects, with some variations, having been adopted, and his exposition of the doctrine of proportions carefully consulted. The work now offered, is not however to be considered as a servile compilation; the former experience of the author as a lecturer, and his habit, for many years, of analysing various substances, having given him opportunities, not only of verifying the deductions of others, but occasionally of making new experiments for himself.

Hartford, November 15, 1831.

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PART II.

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In this "atomic age" the preface statement in Comstock's *Chemistry* which begs the question of whether the atomic theory "be true, or false," is particularly interesting. Note the topics and ordering of content listed in the Contents page at the right above.

If making a telescope and using it seemed a profitable activity, it was done, and the entire group of students and the instructor might take a week off from other work to do the job. Today's school would seldom allow the students prolonged opportunity for "bull sessions" about the meaning of life or for conjecturing on the possibility that intelligent beings might live on other planets. There is too much to cover, and the typical teacher would become restless if more than twenty minutes were spent on such a "profitless" consideration, when, after all, "There are only two more days in which to 'finish' the solar system." But the early academy instructors apparently did not develop guilt feelings because they were not able to "finish" the solar system. After all, they did not have textbooks nor the tradition that coverage is the aim of the science course. They had local

patrons who were interested in having their children learn what could be taught them about the fascinating areas of science that were deemed to be of most value for practical, moral, and social reasons. The teacher was forced, often by his very lacks, to think through his program and to develop it with his students or at least directly for them.

THE NINETEENTH-CENTURY HIGH SCHOOL

The academies in America did not die. They were the stimulus for, and they finally changed into, a new type of secondary education that became known as the "high school." This change from a private, selective, and highly heterogeneous type of secondary education into a public, democratic, and relatively uniform type took place chiefly during the latter half of the nineteenth century. The development of the high school during this period is of particular interest to the science teacher, for he is teaching under a system born and nurtured during this time. His program bears marks of its antecedents in this period as well as in the Colonial and academy periods of American secondary education.

The academies, as has been noted, were private institutions. Their absorption into the high school movement was based, in part, upon the fact that state funds were increasingly being made available for their support without adequate control to be sure that good money was not being sent after bad. A few of the academies were probably little more than farcical institutions in which instruction was offered by quacks. One can guess what might have been the nature of the science offerings in some of the academies that advertised for students in the newspapers of the state of Illinois in 1819 from the criticism offered by a Reverend Timothy Flint during this year. Flint wrote,[3]

> I have been amused in reading puffing advertisements in the newspapers. A little subscription school, in which half of the pupils are abecedarians, is a college. . . . The misfortune is that these vile pretensions finally induce people to believe that there is a royal road to learning. The old beaten track, marked out by the only sure guide, experience, is forsaken. The parents are flattered, deceived, and swindled. Puffing pretenders take the place of the modest men of science, who scorn to compete with him in these vile arts. . . . A respectable man wishes to establish himself in a school in these regions. He consults a friend, who knows the meridian of the country. The advice is, Call your school by some new and imposing name. Let it be understood that you have a new way of instructing children, which they can

[3] *Illinois Intelligencer,* January 6, 1819. Quoted in P. E. Belting, *The Development of the Free Public High School in Illinois to 1860* (Springfield, Ill.: Illinois State Historical Society, 1919), pp. 21–22. Also quoted in I. L. Kandel, *History of Secondary Education* (Boston: Houghton Mifflin Company, 1930), pp. 411–412.

learn, in half the time, as by the old ways. . . . In short, depend upon the gullibility of the people.

On the other hand, some of the academies were definitely superior to the colleges in the country in the soundness of their science instruction. Their offerings stimulated reflection, investigation, and analysis of the facts and principles of science.

Arguments other than the ineptness of the academies were advanced for the establishment of high schools. These rested chiefly on the fact that the academies were exclusive and aristocratic and that they enrolled only those who could pay fees (except for exceptionally able children who, even if their parents could not afford the tuition, were often accommodated through donations).

The importance of the argument that the academies were too exclusive is seen in the statement of the reasons set forth in 1820 for the establishment of the first high school in this country, the English Classical School for boys, which was started in Boston two years later. The committee of townspeople which investigated the need for such a school stated that the schools of the time had "the effect of excluding many children of the poor and unfortunate classes of the community from the benefits of a public education." The school that was established on the basis of this committee's recommendation came to be known as the "English High School."

Tendency toward Standardization

It has already been noted that the science offerings in the academies were highly variable and depended upon the wishes of the local patrons and the abilities of the instructor or instructors. It has also been indicated that the instructional procedures as well as the content of the courses varied tremendously. Despite the advantages to be found in such a free climate, it is quite obvious that there was little to prevent slipshod work and the purveyance of trivia. An impossible situation was created for the colleges that were forced to accept the products of the lower schools into their hallowed halls. The desires of the colleges for some control over the preparatory functions of the schools created the first attempts at standardization of secondary education.

The legislature of the state of New York (where centralized control of education has been prominent from the earliest days of the secondary schools) established a Board of Regents in 1784. The task of this board was to control as well as to establish schools and colleges.

The Regents did little or nothing to define the curricula of the academies, however, and, for many years, nothing was done to attempt to standardize the rather chaotic offerings of these institutions. But the Board of Regents was the first of a large number of accrediting and standardizing agencies that had achieved a certain, and very real, controlling influence over the secondary schools of the country by the end of the nineteenth century.

OUTLINES

OF

GEOLOGY:

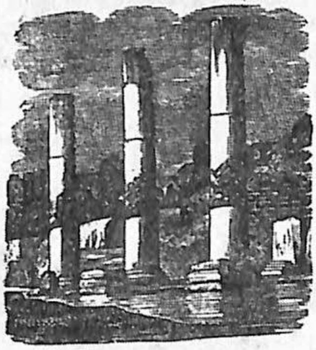
INTENDED AS A POPULAR TREATISE ON THE

MOST INTERESTING PARTS OF THE SCIENCE.

TOGETHER WITH AN EXAMINATION OF THE QUESTION,

WHETHER THE DAYS OF CREATION WERE INDEFINITE PERIODS.

DESIGNED FOR THE USE OF SCHOOLS AND GENERAL READERS.



BY J. L. COMSTOCK, M. D.

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THIRD EDITION.

NEW YORK.

ROBINSON, PRATT, & CO.

63 WALL STREET.

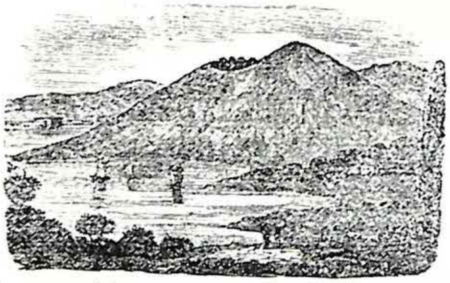
1839

Note the special reference in this title page of Comstock's *Geology* to the touchy topic of creation as told in Genesis and as determined through geological timetables. The science of early schools often was used to lend support to the deistic conception of God.

mal baths which existed there. On the evening above mentioned, after many previous shocks of an earthquake, the ground opened in the form of a wide fissure, which ran towards this town, with a tremendous noise, accompanied with the discharge of pumice stones, blocks of lava, and ashes. At the same time a gulf, of considerable extent, opened in the suburbs of the town, by which many houses were swallowed up. The sea also retired, leaving its bed naked along the shore.

The fissure which had reached the town, continued to discharge volcanic matter for 36 hours, during which time, its quantity was such as to form the mountain in question.

Fig. 9.



The annexed drawing, fig. 9, will show the form of this mountain. No. 1, the mountain. No. 2, a part of the crater. Its height has been lately determined to be four hundred and forty feet above the level of the bay of Naples. Its base is eight thousand feet, or nearly a mile and a half in circumference, and the depth of the crater, four hundred and twenty-one feet from the summit, so that the bottom of the crater is only nineteen feet above the level of the sea.

No lava flowed from this crater, but the matter ejected, which fell down and formed the mountain, consisted of masses of ancient lava, ashes, pumice, and slaty stones. These blocks of ancient lava, prove the volcanic origin of the ground below the present mountain.

We have thus given such an account of volcanoes, earthquakes, and the elevation of islands and land, by subterranean fire, as our limits will allow.

The design of these facts, is not merely to satisfy the curiosity of the reader, but, as will be seen in the sequel, to account for phenomena which the earth presents, by showing an analogy between the effects of known and unknown causes. Thus, the earth almost everywhere indicates, by the position of its strata, that its crust has been disturbed by subterranean forces; and marine remains show that a great proportion of the dry land has once been under the sea. That these changes have been effected by the same cause which elevates islands from the sea, at the present day, we shall endeavor to show in another place.

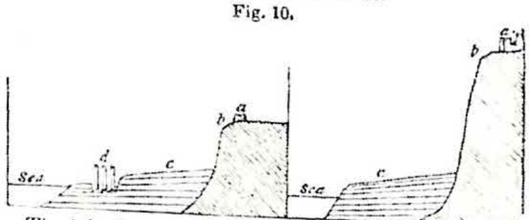
Temple of Jupiter Serapis. In a few instances, it is known that portions of land have several times changed their level, with respect to that of the sea; and of which the following is an interesting and curious example.

The temple of Serapis, a celebrated monument of antiquity, is situated on the little bay, called Baiæ, within the bay of Naples.

A geological examination of the coast of Puzzuoli, along this bay, shows that the land has been elevated about twenty feet, at a period not very remote, so that, without the evidence presented by the temple, there is sufficient proof that the land in the vicinity has changed its level.

If the coast along the shore, between Naples and Puzzuoli, be examined, it will be seen that the tract of fertile land which intervenes between the present shore, and the high, rocky cliffs, was evidently once under the water, and that the ancient shore was near these cliffs.

Fig. 10.



The inland cliff near Puzzuoli, is in many places about eighty feet high, and quite perpendicular. At its base, the new deposite attains the height of twenty feet above the sea. This consists of sedimentary matter, mixed with marine shells, showing that it was formed under the water.

Comstock's *Geology* dealt, as its title page stated, with the "most interesting parts of the science." These pages describe the volcanic action of the land around the Bay of Naples, Italy (Vesuvius, etc.), and discuss the alternating subsidence and elevation of the famous Temple of Jupiter Serapis at the edge of the Bay.

It was nearly a hundred years after its establishment that the Board of Regents began a system of control that has continued down to the present time. In 1864, it established preliminary examinations for college entrance, and in 1877, it set up examinations that provided standards both for graduation from high school and for admission to the colleges of the state of New York. Teachers of science who were unwilling or unable to determine their own objectives now had a lodestar to guide them.

In 1880, the Regents began to issue syllabi to the secondary schools of the state, and, in 1890, the Board established, for the first time in the country, a system of "counts" whereby the "equivalence" of subjects could be determined on the quantitative basis of total periods of instruction. The "count" repre-

sented ten weeks' work in a course in which the student recited five times a week. Various branches of a subject field, including science, were specified. By 1895, there were ten specified branches of science which allowed a student to accumulate a total of twenty "counts." This system of counts was soon the established means of standardizing the curriculum all over the United States. The old academy system of teaching science without a centrally produced syllabus, under a completely flexible system of time and order, and without preconceived or dictated terms of coverage fast changed to a conception of uniformity in structure, units of credit, and similar coverage. Time spent in the science classroom became the chief constant for all children.

Tendency toward a Broader Curriculum

It is rather odd that two basically conflicting tendencies conspired to bring the new high schools into being. One of these tendencies was the growing pressure toward standardization which has been discussed. The other was the growing pressure for universal, free secondary education based upon a broader curriculum foundation than that commonly provided by the academies. The one force tended to restrict the science offerings and to mold them into a uniform pattern. The other tended to emphasize the social basis and personal worth of the school offerings, including science. This emphasis promoted programs that varied according to individual and local needs. That the former won does not alter the fact that the entire high school development was predicated on the assumption that a democratic government without an informed citizenry "is a prelude to a farce and a tragedy." The argument was clearly expressed by Horace Mann in 1849. He stated,[4]

> Under our republican government it seems clear that the minimum of education can never be less than such as is sufficient to qualify each citizen for the civil and social duties he will have to discharge; such an education as teaches the individual, the great laws of bodily health, as qualifies for the fulfillment of parental duties; as is indispensable for the civil function of a witness or a juror; as is necessary for the voter in municipal and national affairs; and finally, as is required for the faithful and conscientious discharge of all those duties which devolve upon the inheritor of a portion of the sovereignty of this great Republic.

This and other implied or direct criticisms of the academy and early high school programs of the time and their philosophy of secondary education are still being voiced today in reference to conventional high school offerings. Of course, one could quote extensively from the educational philosophers of all periods of history and, by changing the language and word structures peculiar

[4] *Tenth Annual Report of the Massachusetts Board of Education* (1849), p. 17. Quoted in Kandel, *op. cit.*, p. 441.

to these times, cause the reader to believe that they were from the latest policy statement of a national commission. But our interest, here, is those viewpoints that influenced the form and structure of the American high school and, therefore, the nature of science offerings and science teaching.

One of these viewpoints, reflecting the earlier concepts of Comenius, Rousseau, and others, and foreshadowing the emphasis, today, on educating the individual in terms of his own promise and individual potentialities, was expressed by Emerson, who assiduously attacked the growing tendencies toward uniformity in educational procedures and standards of evaluation. He wrote,[5]

> I suffer whenever I see that common sight of a parent or senior imposing his opinion and way of thinking and being on a young soul to which they are totally unfit. Cannot we let people be themselves, and enjoy life in their own way? You are trying to make that man another *you*. One's enough. Or we sacrifice the genius of the pupil, the unknown possibilities of his nature, to a neat and safe uniformity, as the Turks whitewash the costly mosaics of ancient art which the Greeks left on their temple walls. Rather let us have men whose manhood is only the continuation of their boyhood, natural characters still; such are able and fertile for heroic action; and not that sad spectacle with which we are too familiar, educated eyes in uneducated bodies.

The science teacher today can well ponder the significance of this statement. He may profitably consider the degree to which conventional programs of science are attempting to stretch or diminish students to fit the pattern of a constant content, uniformly organized, and taught to young people who are widely different from one another. It is in the very differences among people that potential genius and creativity lie. Outstanding contributions to the fields of science, the work of the community, and the life of a democracy may be expected from exceptional—not average—persons. Individuality should be fostered, not diminished.

Increasing Uniformity in Science Instruction

Whatever the situation today, Emerson's point of view did not win out during his time. On the contrary, as an accrediting system grew in the United States, uniformity became increasingly necessary.

In 1870, a system of accrediting high schools in order that their students might enter colleges without special entrance examinations was established in the state of Michigan. The plan had merit in that it brought the high schools and colleges into closer articulation and in that the schools were subsequently freed from the necessity of preparing their students for specific entrance examinations.

[5] R. W. Emerson, *Letters and Social Aims*, p. 291. Quoted in Kandel, *op. cit.*, p. 451.

(Science teachers who have "boned" their students for the Regent's examinations in New York State and similar examinations in other places will recognize that the advantage is not a small one.) The system spread quickly to other states in the Middle West and Far West. General inspection of high school programs, facilities, and staff by "high school visitors," became the order of the day in many states. This permitted the establishment of general standards and tended to avoid the necessity of a preoccupation with an examination system.

But the system did have the effect of narrowly standardizing the programs of the sciences and other courses on a state-wide basis. Clearly, this had its good and its bad features. The values have briefly been suggested and are rather obvious. The harmful results derived chiefly from the fact that uniformity became conformity to a set of standards and goals established largely by university personnel and designed almost exclusively on the subconscious assumption that the high school was solely a college-preparatory agency not only in its general purpose but also in terms of specific programs of physics, chemistry, and biological sciences. The colleges were beginning to call the educational tune, and all the students—whether or not college-bound—were forced to quicken the tempo of their learning to a constant beat struck by the demands of the specialists. Science instruction began to take on its present characteristics of a timed race over facts. Uniform coverage became the order of the system. Children from farms and children from metropolitan areas, the "dull" and the "bright," the college-bound and the potential factory worker—with vast differences in their backgrounds, experiences, needs, and goals—began increasingly to study science as an organized and internally structured discipline.

The growth of regional accrediting associations. In 1879, a conference of New England colleges was held for the purpose of securing some degree of interstate uniformity in accrediting secondary schools. The New England Association was the outgrowth. In 1892, the Association of Colleges and Preparatory Schools of the Middle States and Maryland was formed. The purpose of this association and, indeed, the major purpose of all regional accrediting associations was stated by the former as follows:[6]

> The object of the Association shall be to consider the qualification of candidates for admission to college and the methods of admission; the character of the preparatory schools; the course of study to be pursued in the colleges and schools, including their order, number, etc.; the relative number of required and elective studies in the various courses . . . .

No better or more accurate statement need be found to indicate the tremendous power that the regional accrediting associations have had in the past on the purposes, detailed objectives, and teaching methods of high school teachers. The science teacher will find in this statement many of the reasons why his science

6 Quoted in Kandel, *op. cit.*, p. 468.

courses are organized as they are. He will note in this statement that the purpose of this particular association, at its founding, was not to secure merely a general standardization of the science program. It was to secure definite conformity in the "character" of the schools, "the course of study to be pursued," "the relative number of required and elective studies," and even the "order" and "number" of the courses.

It should be stressed that the accrediting function of the regional associations has changed markedly over the past decade or two and that most of them today are fostering rather than hindering flexibility and heterogeneity. But their influence on American education in the late nineteenth century and the early decades of the twentieth century remains—and heavily affects—the science courses offered in this country today.

The college-entrance examination. The growth of the regional associations was contemporaneous with the development of an examining system designed to provide graduates from schools anywhere in the United States with a uniform battery of college-admission examinations, success in which would permit them to enter any college utilizing the system. Tens of thousands of students still take these examinations each year, and the results of their examinations are sent to the appropriate colleges as a basis for considering their qualifications for entrance. This, too, influences the nature of the science offerings, for the results of the examinations become known in the local community and the quality of the science instruction may be popularly judged by the results of these examinations of a few students who are college-bound and who subscribe to this method of screening. The science teacher would be an unusual psychological type who did not bow somewhat to the pressure on his teaching created by public announcements of his students' successes and failures on such examinations. "This year, out of twelve students who took the college-entrance examinations, all but one 'passed' and were admitted to the college of their choice." Excellent! But there is considerable evidence that the examinations do not predict a student's ability to remain in college and to do well after he is admitted. Several studies, such as those by Crawford and Burnham,[7] have shown that there is a rather weak relation between these examination results and later college success.

Many teachers work harder and harder to teach the things (however verbalistic) that are required so that a few may pass the tests with high honors, and the great majority of the children are lashed by the same whip. On the basis of modern knowledge of the learning process and experimental evidence from valid studies (see Chapter 5) all suffer, including the college-bound youngster and the student with high ability who might become a creative scientist of tomorrow.

The report of the Committee of Ten. It would be unfair and not consonant with the facts to imply that the entire standardization movement was without value. In the last decade of the nineteenth century, many high schools were

[7] A. B. Crawford and P. S. Burnham, *Forecasting College Achievement* (New Haven, Conn.: Yale University Press, 1946), Part I.

becoming almost chaotic in the range and multiplicity of their offerings. Some standardization and uniformity was clearly called for. There was, at this time, no general agreement concerning the proper function and responsibility of the high school and of the science teacher.

In 1892, the National Education Association appointed a committee under the chairmanship of President Charles W. Eliot of Yale University to consider the condition of secondary education and to offer recommendations.

The committee was not without bias, for it was composed of ten specialists who ignored completely certain phases of the curriculum (arts and humanities, for example). Conferences were set up on a number of subjects, among them physics, astronomy, and chemistry; natural history (biology, including botany, zoology, and physiology); and geography (including geology and meterology).

The men working in the three science areas, and those in the other areas as well, were given a list of questions which revealed the responsibilities with which they were changed. They were to determine the age at which the subject should be begun, the number of hours per week that should be set aside for it, the number of years that should be devoted to it, the topics that should be covered, the methods of teaching that should be employed, and so on.

The Committee of Ten issued its report in 1893. It stated, in general, that certain subjects, including science, should be begun earlier in the schools (here was the birth of the junior high school program); that there should be no distinction in the offerings in science provided for those going to college and those not going to college (uniformity in offerings for all comers); *and that all should be taught in the same way!*

This last recommendation, with its complete shrugging off of the facts of individual differences in backgrounds, abilities, and goals, was a notable defect in the report, from a modern viewpoint.

Nonetheless, the committee stated, without qualification,

> The secondary schools of the United States, taken as a whole, do not exist for the purpose of preparing boys and girls for colleges. Only an insignificant percentage of the graduates of these schools go to colleges or scientific schools.

The committee further stated that a college should accept for admission credit any group of studies, provided that the sum of these in each of the four years amounted to sixteen periods a week at a minimum, and provided, further, that in each year at least four subjects had been taken at least three periods a week, and, finally, that at least three subjects had been taken for three years or more.

The significance of these recommendations can hardly be overemphasized. For one thing, the report supported the principle of the equivalence of studies. The statement made clear that the committee held that the colleges should accept for admittance credit any subject or group of subjects (under the committee's purvue) on an equal basis of time spent. It stated, further, the principle that at

least three subjects should be studied over such a period of time—three years—as to enable the student to develop a substantial grasp of the area.

Here, in 1893, was a report that was to become highly influential, that, in effect, told the colleges that they should not attempt to determine the high schools' curricula by demanding that students be subject to particular programs in which the required courses for college entrance were specified. There was, in this recommendation, an implied belief in the efficacy of mental discipline (the belief that the mind is composed of "faculties," such as memory, which, if trained and developed in one field, will operate as effectively in another field). But, even if some of the reasons behind the committee's thinking were incorrect, the principle of equivalence of subjects for college-entrance purposes that it enunciated has repeatedly been shown to be valid on the basis of empirical studies (see Chapter 4). It is a matter of interest and regret that, as will be shown later, the science conferences of the committee ignored the nonpreparatory conception of the high school enunciated by the Committee of Ten. The house was divided against itself.

The Committee on College Entrance Requirements. Another committee was appointed, at about the same time as the Committee of Ten, to study the question of college-entrance requirements. The report of this committee, as it affected and affects science, stated,[8]

> While it also recognizes the principle of large liberty to the students in the secondary schools, it does not believe in unlimited election, but especially emphasizes the importance of a certain number of constants in all secondary schools and in all requirements for admission to college.
>
> . . . the number of constants be recognized in the following proportion, namely: four units in foreign language . . . , two units in mathematics, two in English, one in history, and one in science.
>
> . . . in general we recognize in schools the admissibility of a second year in advanced work in the same subject, instead of a second year in a related subject; for example, two years in biology instead of one year in biology and one year in chemistry, where local conditions favor such an arrangement.

If the reader has ever wondered why it is that one year of a laboratory science is commonly required for high school graduation and, in general, as a minimum for entrance to many colleges, the second recommendation quoted above will give him his answer. Enunciated in 1899, it is still the common requirement in the majority of high schools today.

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[8] National Education Association, "Report of the Committee on College Entrance Requirements," *Journal of Proceedings and Addresses,* 38:661–664, 1899.

The "Carnegie Unit." The report of the Committee of Ten consolidated the principle of equivalence of courses by its insistence that[9]

> the colleges [should] state their entrance requirements in terms of national units, or norms, and . . . the schools [should] build up their programs of studies out of the units furnished by these separate courses of study.

Shortly afterward, the Carnegie Foundation for the Advancement of Teaching utilized this standard unit—"a unit is a course of five periods a week throughout an academic year"—in evaluating college standards in connection with a study leading to proposals for pension systems for college instructors. The unit had become the standard and universal American index of credit for both high schools and colleges. Gone for good was the freedom of the days of the academy and the early high school when a science teacher taught his subject and his students with fine abandon and disregard for the niceties of class hours and time.

Use of the unit had to come, and modern schools would be thrown into complete chaos if it were abandoned overnight. But the science teacher can well wonder whether the accumulation of a certain number of units, even in natural sciences, is synonymous with the development of an educated and capable individual and citizen. "How many units have you had in physics?" may often cover up the far more fundamental questions, "How would you tackle this physical problem?" "How would you proceed to analyze this situation?" "How does your understanding of physical principles influence your judgment on this issue?" "Where would you go to get valid information on this matter?" and the like. We should not let use of the unit blind us to the substantive questions in our field.

Additional factors: teacher preparation and the textbook. Despite its values, the report of the Committee of Ten in 1893 was not entirely salutory in its effect on the development of science teaching in the United States.

Although the report of the committee held that the main function of the secondary schools "is to prepare for the duties of life that small proportion of all the children in the country who show themselves able to profit by an [high school] education . . . ," the specialists in the conferences in science ignored this mandate and not only laid the foundation for college entrance units but, in effect, defined the prime purpose of science teaching in terms of college preparation.

These science conferences and their report produced a chain-reaction effect that determines the nature of conventional science teaching today, for it established a pattern of teaching objectives, textbook organization, laboratory work, and even teacher preparation in science subjects at a time when it was thought that only a "small proportion of all the children in the country" could profit from a secondary education. Today, the high schools are charged with the

[9] *Ibid.*, p. 672.

responsibility of educating "all the children of the people." Yet, the pattern established through the science report remains fundamentally the same today as far as the organized high school subjects of physics, chemistry, and biology are concerned. The great change in student enrollment and the need of the mid-century world for a citizenry literate in science have not fundamentally altered the pattern of science courses brought into being by the specialists in the science conferences in 1893.

The report did not directly affect the classroom teacher. The college-preparatory emphasis of the science report was implemented by statements from other committees and in reports and books directed to the classroom teacher. The report of the Committee of Ten, the 1899 report of the Committee on College Entrance Requirements of the National Education Association, and the controls of the College Entrance Examination Board were all influential in establishing the pattern of science teaching that is still prominent in American schools.

Other factors were also influential. Patterns of teacher preparation in subject-matter fields became fairly uniform before the turn of the century. Courses in college science for the science teacher were rarely developed in terms of the teacher's professional needs. The teacher in training was under the necessity of taking courses most of which were designed primarily for the preparation of research workers in the field or for such professions as medicine and engineering. This is still true today. Science training for the high school teacher has not helped him to see what science means in the lives of his students or in the life of the community to which he is responsible. It may have given him a good start on the road to research work or to being an engineer or a medical doctor. It has given him too little help in understanding his role as a teacher and what science he might teach with profit to his students. The *professional* needs of the teacher are almost wholly ignored in the academic departments of most institutions. This pattern, too, was set in the past.

Books began to appear on the teaching of secondary school science soon after the reports of the Committee of Ten and the Committee on College Entrance Requirements. They generally showed the influence of these reports. One such book was that of Lloyd and Bigelow,[10] which was designed for teachers of biology and which interpreted and extended the report of the Committee of Ten. This book set forth certain principles that, it was held, should be prominent in the mind of the teacher of biological sciences.

Another book,[11] on the teaching of botany, was published in 1910, and, for a while, this subject claimed a large high school enrollment. However, the Committee on College Entrance Requirements had recommended that botany,

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[10] F. E. Lloyd, and M. A. Bigelow, *The Teaching of Biology in Secondary Schools* ("American Teacher Series"; New York: Longmans, Green & Co., Inc., 1904).

[11] W. F. Ganong, *The Teaching Botanist* (New York: The Macmillan Company, 1910).

zoology, and human physiology be combined into a one-year course in biology, and this was soon an established practice over the country.

Perhaps even more influential in standardizing science courses was the book written by a professor of physics and a professor of chemistry,[12] both of whom had been chairmen of National Education Association committees. This book clearly lays down a pattern for the teaching of physics and chemistry, a pattern dictated by considerations of college-entrance requirements. All these books contained excellent help for the science teacher, but they were fundamentally in support of a standardized, college-preparatory conception of high school science teaching.

While these influential books for teachers were being published, the textbook houses were not asleep. Textbooks by the score rolled from the presses. By and large, they show both the influence of the committee reports and the specialized training and concerns of the authors who wrote them.

It would be unfair to suggest that the textbook publishers and authors attempted to stereotype the teaching of science through the curriculum materials they made available. Publishers and authors then, as now, were simply responding to the best of their ability to the demand of the teachers in the field. But the effect was further standardization of science teaching. However, some extraordinarily forward-looking books were also published during this first decade of the twentieth century. Almost without exception, these were in the field of biology. It was not until the 1940's that forward-looking books in physical sciences began to appear, and even then there were not many. One of the most widely used and the most valid earlier texts, from a modern point of view, was George Hunter's *Elements of Biology*, which was published by the American Book Company in 1907. Hunter was, at that time, head of the department of biology of the DeWitt Clinton High School in New York City, and he had been a prominent member of the biology committee which prepared the syllabus for the teaching of biology which was published and issued by the New York State Department of Education. His book was adopted throughout the state of New York and, in the course of about forty years, was widely used, primarily through city and state adoptions, throughout the United States.

The influence of science textbooks throughout the country soon became tremendous. Uniformity of science instruction has been securely established. State and city syllabi were often based upon the textbook adopted, and one could go into any chemistry, physics, or biology class in any high school in one of several major cities and know ahead of time what he would observe being taught, say on the fifth day of April of any year. The needs of children, their tremendous differences in ability, interest, background, and purposes, were generally ignored in the hurry to cover the facts that were presented in the textbook. The textbook,

[12] Alexander Smith, and E. H. Hall, *The Teaching of Chemistry and Physics in the Secondary Schools* ("American Teacher Series"; New York: Longmans, Green & Co., Inc., 1902).

in turn, too often reflected a now completely discredited mental-discipline psychology and a conception of college-preparatory instruction that must be seriously questioned, not as a goal, but in terms of what leads to college success and leadership qualities.

Prefaces to science textbooks, as well as educational literature of the period from about 1860 to 1920, abound in such statements as the following: "The practical benefit—is the discipline which it gives the mental powers." "The study of zoology can be made of highest interest and value calling out both the observing and reflective faculties." "It is in the highest degree beneficial to the young partly because of the facts which it imparts but even more on account of the mental power it develops."

SIGNIFICANT POLICY REPORTS OF THE TWENTIETH CENTURY

In 1913, the National Education Association appointed a Commission on Reorganization of Secondary Education. In 1918, this commission published a report[13] in which it listed seven "cardinal principles" to serve as a guide for the redirection of high school education. As this report had far-reaching influence throughout American education and still represents an acceptable point of view to most educators, the seven principles are presented in abbreviated form below.

> *Health:* The secondary school should . . . provide health instruction, inculcate health habits, organize an effective program of physical activities, regard health needs in planning work and play and cooperate with home and community in safe-guarding and promoting health interests.
>
> *Command of fundamental processes:* Much of the energy of the elementary school is properly devoted to teaching certain fundamental processes, such as reading, writing, arithmetical computations, and the elements of oral and written expression. The facility that a child of 12 or 14 may acquire in the use of these tools is not sufficient for the needs of modern life . . . proficiency in many of these processes may be increased more effectively by their application to new material than by the formal reviews commonly employed. . . .
>
> *Worthy home membership:* . . . calls for the development of those qualities that make the individual a worthy member of a family, both contributing to and deriving benefit from that membership.
>
> *Vocation:* . . . education should equip the individual to secure a livelihood for himself and those dependent on him, to serve

[13] Commission on the Reorganization of Secondary Education, *Cardinal Principles of Secondary Education* (Bureau of Education, *Bulletin* No. 35; Washington: Government Printing Office, 1918), *passim.*

> society well through his vocation, to maintain the right relationships toward his fellow workers and society, and, as far as possible, to find in that vocation his own best development.
>
> *Civic education:* . . . should develop in the individual those qualities whereby he will act well his part as a member of neighborhood, town or city, state, and nation, and give him a basis for understanding international problems.
>
> *Worthy use of leisure:* . . . This objective calls for the ability to utilize the common means of enjoyment, such as music, art, literature, drama, and social intercourse, together with the fostering in each individual of one or more special avocational interests.
>
> *Ethical character:* . . . paramount among the objectives of the secondary school. Among the means for developing ethical character may be mentioned the wise selection of content and methods of instruction in all subjects of study, the social contacts of pupils with one another and with their teachers, the opportunities afforded . . . for the development on the part of pupils of the sense of personal responsibility and initiative, and, above all, the spirit of service and the principles of true democracy which should permeate the entire school . . . principal, teachers, and pupils.

This document was a break with the past in terms of basic point of view. Its opening statement declared for a curriculum constantly developing in response to changes in student population and society and to newer knowledge of educational practices. It proposed a curriculum in which each subject field should be reorganized in terms of its potential contributions to the objectives specified in the seven cardinal principles. The place of the subjects in the curriculum, as seen by the committee, is shown by the following statement:[14]

> Each subject now taught in high schools is in need of extensive reorganization in order that it may contribute more effectively to the objectives outlined herein, and the place of that subject in secondary education should depend upon the value of such contribution.

The basic report of the committee was buttressed by sixteen other committee reports, one of which was in science. The subcommittee on science issued its report in 1920.[15] The report stressed the importance of science education for direct and functional values to the student. It also emphasized the importance of a continuous and progressive program from the elementary grades through the college level of science instruction. The science subcommittee's report was

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[14] *Ibid.*, p. 16.

[15] U.S. Bureau of Education, *Reorganization of Science* (*Bulletin* No. 26; Washington: Government Printing Office), 1920.

the first comprehensive report in America dealing entirely with problems of science teaching in the public schools. Its impact, together with that of the general report of the Commission on the Reorganization of Secondary Education, was immediate and widespread on the nation's schools.

Scientific method as an important goal of science instruction was first recommended in a national committee report published in 1928.[16] This report was prepared by a special committee of the American Association for the Advancement of Science. Among other things, the report suggested the desirability of conducting studies of science teaching at the national level and the formation of a national council of science teachers.

One of the most influential documents of science education ever to be issued was the Thirty-first Yearbook of the National Society for the Study of Education.[17] This yearbook, which should be studied by every science teacher, proposed an organized and comprehensive program in science from the first through the twelfth grade. Its most significant contribution—one that widely influenced and still influences American science education—was its insistence that science instruction be organized around the major generalizations or principles of science. This "generalizations" point of view is described in more detail in Chapter 7, but its major theme can be understood from the following:[18]

> The major generalizations and associated scientific attitudes are seen as of such importance that understandings of them are made the objectives of science teaching. . . . They touch life in so many ways that their attainment as educational objectives constitutes a large part of the program of life enrichment. . . . It is proposed that the curriculum in science for a program of general education be organized about large objectives, that understanding and enlargement of these objectives shall constitute the contribution of science teaching to the ultimate aim of education, and that the course of study be so organized that each succeeding grade level shall present an increasingly enlarged and increasingly mature development of objectives.

The report listed thirty-eight generalizations considered to be of such importance as to form the core of all science teaching in the public schools. Each grade, from the first to the twelfth, was to contribute to the student's grasp of these generalizations by providing him with deepening understandings related to the world about him and his place in the natural world. "The sun is the

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[16] American Association for the Advancement of Science, "Committee Report on the Place of Science in Education," *School Science and Mathematics*, Vol. 28 (June), 1928.

[17] *Program for Teaching Science* (Thirty-first Yearbook of the National Society for the Study of Education, Part I; Chicago: University of Chicago Press, 1932).

[18] *Ibid.*, p. 44.

chief source of energy for the earth" is one of the listed objectives and is rather typical of their nature.

In 1938, the Progressive Education Association published a book[19] which presented a comprehensive analysis of the contribution of science to such broad areas of living as personal living, personal-social relationships, social-civic relationships, and economic relationships. Although general in tone and without detailed analysis of science in terms of typical school courses, the report is as timely today as it was when it first appeared. One of its chief contributions lay in its analysis of the use of reflective thinking in the solution of problems.

There have been other important and influential reports during the last few decades. Practically all of these have been of the same philosophical orientation. Two, recent and influential, are the Forty-sixth Yearbook of the National Society for the Study of Education[20] and the January 1953 *Bulletin of the National Association of Secondary-School Principals.*[21] As both these reports should be read in their entirety by science teachers, no attempt will be made here to digest their contents. Suffice it to say that these volumes, like others issued since the report of the Commission on the Reorganization of Secondary Education in 1918, represent a continued attempt to relate science instruction more closely to the needs of youth, to social problems, and to the development of intellectual, emotional, and ethical maturity in young people.

SUMMARY

Science education today bears the imprint of the past. Objectives, organization, and practices variously show the influence of past viewpoints, policies, and theories. As our knowledge of psychology and pedagogy has grown, practices have changed. But change has been slow, and in some practices today we find evidences of long-discredited theories.

The first secondary schools in America were basically authoritarian and anti-scientific. Science entered the schools long after the establishment of these early Latin grammar schools. The scientific revolution and the needs of the young nation forced the introduction of science into the schools. The growth of science programs paralleled the development of the academy movement during the last half of the eighteenth century and the first half of the nineteenth.

The early academies varied tremendously in what they offered to young people. Science courses varied accordingly. But with the introduction of textbooks in the middle of the nineteenth century and the development of modern high

[19] Progressive Education Association, *Science in General Education* (New York: Appleton-Century-Crofts, Inc., 1938).

[20] *Science Education in American Schools* (Forty-sixth Yearbook of the National Society for the Study of Education, Part I; Chicago: University of Chicago Press, 1947).

[21] *Science in Secondary Schools Today*, *Bulletin* NASSP, Vol. 37, No. 26 (January), 1953.

schools, standardization began to develop. Other factors in the standardization of science instruction were the development of college-entrance examinations, the issuance of syllabi by states and city systems, the establishment of a national credit system, and the development of a system of general inspection of high school programs by state authorized "high school visitors." Regional accrediting associations for many years fostered standardization, but in more recent years they have often encouraged experimental departures in school programs.

Early concepts of education emphasized formal discipline and held that instruction should discipline the "faculties" of the mind. These supposed faculties, such as reason, imagination, and perseverance, were thought to be best developed by requiring students to study classical subjects which, through their very difficulty and separateness from the affairs of daily life, would have high disciplining value.

With the report on the seven cardinal principles of education in 1918, a major reorganization of American secondary education toward more functional goals and in consonance with newer insights into psychology and pedagogy began. Science education began to be reshaped accordingly. Over the past thirty years there have been several major reports which have heavily influenced the nature and practice of high school science teaching in the direction of greater functionality.

SELECTED READINGS

COMMITTEE ON CORRELATION OF HIGH SCHOOL WITH COLLEGE CHEMISTRY, "An Outline of Essentials for a Year of High School Chemistry," *Journal of Chemical Education,* April 1936.

This report, now almost two decades old, declared that "in the high schools the viewpoint of the chemistry course should be informational, broadening, and cultural as contrasted with the technical, professional, and specialization attitude which is unavoidable in the colleges."

KANDEL, I. L., *History of Secondary Education.* Boston: Houghton Mifflin Company, 1930.

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THE RESEARCH BASIS FOR MODIFIED PRACTICES

This chapter, although it offers some data concerning newer practices, is concerned chiefly with evidences of the effectiveness of conventional science teaching. We have already defined conventional science teaching by comparing it with newer practices in Chapter 2. It must be understood, however, that conventional practice, in so far as many of the studies reported in this chapter are concerned, covers a tremendous variety of different patterns of content organization and teaching techniques. It is legitimate to group these and call them conventional only in the sense that the great majority of them do tend to represent the pattern designated as "older practices" in Chapter 2. Newer practices of the sort analyzed in Chapter 2 are still too few to have materially affected the results of the studies which will be reported in this chapter.

HIGH SCHOOL SCIENCE AS PREPARATION FOR COLLEGE

Preparation for college has been the chief historical, and probably remains today the most important, influence in determining the character and nature of conventional science teaching, particularly in physics and chemistry. How well has conventional science teaching discharged this important responsibility?

If research discloses that the conventional program of science teaching is doing a good job in preparing youth for success in college work, then it is clear that a function of the highest importance is being well served. We need creative scientists, engineers, technicians, and other scientific workers. Our country is

suffering from a lack of such workers, particularly in the creative areas. The high school science teacher must assume the responsibility of encouraging, nurturing, and offering beginning training to those youths who show promise in science. The question is not whether the need is real. It is emphatically the responsibility of the high school science teacher to prepare his gifted students for college. The question is simply which are doing the better job—the conventional programs or the newer programs.

Studies on the Predictability of College Success

The studies that are pertinent to this question deal, in general, with the examination of what backgrounds, traits, and abilities are most predictive of college success. The results of these studies are expressed as predictive correlations. If students who take our conventional high school science courses and make A's were always to achieve A's in the college equivalents of these courses the predictive correlation would be 1.0. This would indicate that taking a conventional high school physics course with high success would always produce the ability to take college physics with high success. If the high school science course results in no increased power as expressed by grades in college science courses, the correlation would be 0.0. High school grades are rarely used in the prediction studies because the basis of such grades varies so much from teacher to teacher and from year to year. A more accurate basis for determining the predictive value of high school courses are the results of standardized achievement tests which determine certain results of high school teaching.

Measured intelligence is another basis that has been studied for predictive value. If a perfect correlation between intelligence and college success obtained, then any positive correlation between scores on achievement tests and college success would simply represent the functioning of intelligence in the learnings of high school courses. In other words, this would indicate that what was measured by an achievement test was a reflection of intelligence in action and that the knowledge acquired was merely a function of the basically relevant factor—intelligence.

Other factors have also been considered in the predictive studies. Aptitude, average high school marks, specific courses, and patterns of courses, all have been studied. These studies have clearly shown that success in college can best be predicted on the basis of intelligence coupled with reading comprehension and average high school marks which reflect the complex of attitudes and skills that might be epitomized as self-responsibility and study ability. Scores on achievement tests in specific subjects, on the other hand, provide the lowest predictive correlations. Following are the data that support these assertions.

Kinney,[1] Segel,[2] and Durflinger[3] have found median correlations between meas-

[1] L. B. Kinney, *A Summary of the Literature on the Use of Intelligence Tests in Colleges and Universities* (Minneapolis: University of Minnesota Committee on Educational Research, 1932), mimeographed.

ured intelligence and college academic success of .44, .44, and .52, respectively.

In a sense, these studies merely prove the obvious: Intelligent students tend to do better in college than less intelligent students. But the correlation is by no means perfect. Many investigators have found that the correlation improves and that more accurate individual prediction is possible for students at either extreme of the range of intelligence than for those near the median in intelligence-test results. This, again, is not surprising. Highly intelligent students can more confidently be expected to succeed in college than those of average intelligence. Those of quite low intelligence are more consistently likely to fail than those of average ability. What is somewhat surprising is that a minimum measured intelligence needed for college success cannot be stated in categorical terms. Kirkpatrick and Rupp[4] found that, although 80 per cent of freshmen in college with I.Q.'s of 126 or above became seniors, 60 per cent of freshmen with I.Q.'s below 116 also became seniors. Many investigations have shown that, except for students of very high or very low I.Q.'s, it is dangerous to attempt to predict success in college on the basis of intelligence alone.

Let us ignore this intellectual factor, as such, for a while and assume that students have had our courses both in sciences and other academic subjects. Let us give them achievement tests such as the Cooperative tests in these fields. Let us examine the records our students make in college and determine whether or not their results on our achievement tests are good indexes of college success. Many such studies have been conducted. Segel[5] grouped several of these and found a median correlation of .545 between general-achievement tests (testing knowledge and usage of all the major-subject disciplines) and college scholarship. This means that a battery of achievement tests can be given to a student and better prediction of his likelihood of succeeding in college can be secured, on the average, than could be discovered by the use of intelligence tests. But, again, the correlation is quite low for accurate prediction. It is surprisingly low, in fact; for achievement tests cannot exclude the operation of the intelligence factor, yet the correlations are but slightly higher than those obtained when intelligence, alone, is plotted against college success.

It is interesting, therefore, that aptitude tests are found to be quite as reliable as the far more time-consuming achievement tests in predicting college success. The studies of Crawford and Burnham[6] support this. Note the implica-

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[2] David Segel, *Prediction of College Success* (U.S. Office of Education, *Bulletin* No. 15; Washington: Government Printing Office, 1934), p. 69.

[3] G. W. Durflinger, "The Prediction of College Success: A Summary of Recent Findings," *Journal of the American Association of College Registrars*, 19:68–78, 1943.

[4] F. H. Kirkpatrick and R. A. Rupp, "The Pintner Test at the College Level," *Journal of Educational Research*, 33:357–359, 1940.

[5] Segel, *op. cit.*, p. 70.

[6] A. B. Crawford and P. S. Burnham, *Forecasting College Achievement* (New Haven, Conn.: Yale University Press, 1946), Part I.

tions of this fact. The student who has an aptitude for the study of college subjects, including science, without reference to learned facts and principles as tested in achievement tests, can be predicted to succeed in college just as accurately as can the student who has taken these courses and succeeds well on tests designed to measure learned achievement. In effect, then, it would appear that the aptitude for academic work is the really significant factor that is being tested even in the achievement tests.

As a matter of fact, we do not even need to give aptitude tests if we want to predict college success upon the basis of a single gauge. Segel[7] has found that average high school marks and college scholarship correlate with a median coefficient of .55. This is higher than the median coefficients found between intelligence and college scholarship, and it is higher than that found between either general achievement or aptitude and college scholarship.

Interestingly enough, it does not seem to make much difference whether a student has had physics, chemistry, biology, general science, or any other particular course or pattern of courses. Douglass[8] has found that the relationship between patterns of high school subjects and college success is negligible and affects the correlation with college success very little. Others have found the same thing to be true.

Let us now narrow our sights a bit and focus directly on the science courses and their apparent relation to college success. A most revealing study to those who believe that taking a particular course, such as chemistry or physics, will make a difference in the quality of college work that a student later does is that reported by Kronenberg.[9] At the General College of the University of Minnesota, he matched students who were in special status because they had not taken certain subjects ordinarily required for admission with other students of equal ability who had taken these courses in high school. He found that there was no significant difference in the college scholarship of the two groups.

The most comprehensive study on this point was the eight-year study, which has been referred to in an earlier chapter. This study clearly showed that specific subject-matter patterns and types of high school preparatory courses are not essential for academic success of students in college.

Let us focus even more sharply. To what degree is the ability demonstrated by a student in a conventional chemistry, biology, or physics class in high school an indication of the ability that he will later show in the college equivalent of that same course? It should be somewhat indicative, if for no other reason than

[7] Segel, *op. cit.*, p. 70.

[8] H. R. Douglass, *The Relation of High School Preparation and Certain Other Factors to Academic Success at the University of Oregon* ("Educational Series," University of Oregon Publications, Vol. 3, No. 1: Eugene, Ore.: University of Oregon Press, 1931).

[9] Henry Kronenberg, *Validity of College Entrance Requirements* ("Studies in Articulation"; University of Minneapolis Committee on Educational Research, 1937), pp. 61–83.

that the highly intelligent student will tend to do well in the high school course, and, as we have seen, intelligence correlates positively with college success.

There are several studies which show that, in general, the average high school mark of a student in all his studies correlates higher with his success in such a single college course as physics, chemistry, or in biological sciences than does the student's mark in that particular course in high school. In other words, it is a safer bet in estimating how well a student will do in college chemistry to determine his average high school mark than it is to determine how well he does in high school chemistry alone. Both the volumes edited by Jones[10] and the article by Pressey[11] report on this fact.

Now let us deal with aptitude tests in the specific fields of chemistry and physics. An aptitude test does not determine the results of instruction. It does not determine what a student knows in a subject field. It determines with what facility a student can attack situations, problems, and learnings in a field. Tests of specific attitudes in both chemistry and physics have disclosed correlations of .51 with college success in these same subjects. Segel's[12] bulletin reports on these studies. Clearly, then, such tests mean more in predicting how well a student will do in a college course in physics or chemistry than tests given after a high school course which attempt to determine what a student learned, for specific achievement tests in both chemistry and physics correlate only .32 with college success in the same subjects.

This provides an interesting hypothesis. Since the facility and ability with which a student can attack problems, situations, and learnings in these fields appear to be more indicative of college success in these subjects than do learnings in the subjects, perhaps more attention paid in high school science courses to the methodology of problem solving, critical analysis of the literature, and so forth, will produce students of greater promise than our conventional attempt to cover the fields of content. We typically cover content with such speed that we do not have time to encourage the development of the critical and reflective thought processes. This, at least, is the hypothesis. It is a logical one supported by the foregoing data.

Can we test the hypothesis? It has been tested, in part, both directly and indirectly. The indirect test will be discussed first.

The highest correlations that have been found are those that result when general college scholarship has been checked with the combination of average high school marks, results of intelligence tests, and a test of English usage and reading comprehension. Edds and McCall[13] found a multiple correlation of .81

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[10] E. S. Jones (ed.), *Studies in Articulation of High School and College* (2 vols., Buffalo, N.Y.: University of Buffalo, 1934, 1936).

[11] S. L. Pressey, "Credit by Examination: Present Use and Future Need," *Journal of Educational Research*, 38:596–605, 1945.

[12] Segel, *op. cit.*

[13] J. H. Edds and W. M. McCall, "Predicting the Scholastic Success of College Freshman," *Journal of Educational Research*, 27:127–130, 1933.

when this was done. Douglass[14] found approximately the same coefficient from a similar multiple correlation.

What is the significance of this, and how does it indirectly test the hypothesis? Apparently, that student will tend to do well in college courses (including college science courses) who, in general, has demonstrated that he knows how to study and to get along well in academic work, as exemplified by good average high school marks (and it should be reiterated that what subjects are taken is of little consequence), who has a high intelligence, and who can demonstrate that he can profit from study of printed materials, which he will be obliged to read once he gets to college. Such a student, if he has drive and has an interest in science, is almost certain to do well in college work in general and in science work in particular. Perhaps our chief tasks, as far as college preparation is concerned, are to stimulate and challenge our students so that they develop a strong interest in science (and we know how to do that for most students), to demand that they take responsibility for tackling problems on their maturity level and working them out to successful conclusions, and to help them learn better how to use and profit from reference materials of various sorts. We must locate students of promise. We must give them encouragement and assistance in learning as much science as they can while they are still in high school. We should help them to get into college. We need the scientists that such students are likely to become. They cannot be found by chance or hunch alone. They cannot be helped by being placed in a routine physics, chemistry, general-science, or biology class and left to loaf their way to boredom and distaste for science. They must be challenged, inspired, and encouraged to do rigorous, creative, and experimental work while they are still in high school. And if we can locate them and start them on their way in the elementary school, so much the better. It is possible to do so. It requires informed, insightful, and willing teachers if it is to be done.

What are the results of direct testing of the hypothesis? In various parts of the country, there are schools that have utilized the findings of modern psychology and curriculum research and have modified their programs. Some of these schools have followed up their graduates and know what they have done, academically, in college. They have typically done well. These data are rather fugitive, and analysis of them would require more consideration of limiting conditions than space affords. Let us, therefore, examine the findings of the eight-year study, which is the most comprehensive and carefully designed study of the type. In this study, thirty cooperating schools were released from the usual requirements of college preparation, and they varied in their experimental departures from a very small to a significant extent. The general trend in the experimental schools was in the direction of programs, including science, in which students and teachers shared the job of determining the problems and issues to study, the ways of studying them, and the handling of the data secured.

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[14] Douglass, *op. cit.*, p. 49.

The most experimental science classes could be described as problem-centered, with activities planned and executed by the group and as classes in which concern about precise subject-matter lines, coverage of content, or constant achievement or mastery for all did not obtain. They were classes, too, in which considerable reference work, experimentation on science problems encountered by students outside of school, and contacts with the community were common. They were classes in which a great deal of group discussion was carried on, in which the group and the individual students accepted responsibility and exercised self-discipline, and in which imposed discipline was rare.

When the students from the experimental schools went to college they were each separately matched with another student from a conventional school on the basis of scholastic aptitude, major field of study, sex, age, and size and type of high school attended.

What were the results? The students from the experimental schools received grade averages higher in every subject, except foreign languages, than the averages of the students from the conventional schools. They achieved more academic honors and more nonacademic honors; they were more commonly believed to be self-directive; they were more informed about current affairs; they more commonly participated in the active forms, and enjoyed the passive forms, of all the arts. When the students from the six most experimental schools were compared with their peers from the conventional schools, the superiority of the former was even more marked in each of these achievements.[15]

If you have received the impression that it is fruitless to offer instruction in high school science which will be of value to a student who goes on to college work, you have been led sadly astray. It is the conventional, uniformly paced, textbook-dominated, teacher-dominated, verbalistic course that is being criticized. And the criticism is based on considerable evidence, some of which has already been presented. Conventional courses were originally established primarily for college-preparatory purposes, during a time when we knew much less than we now know about the nature of the learning process, motivation, and so forth. They are, today, extremely poor for the purpose, in terms of modern college needs. Many college professors, including professors of science, appear to be unaware of this fact, but this does not make it less true. What are the circumstances and facts that support this as a valid contention?

College science is highly repetitious of high school science. Any physics or chemistry teacher who employs a conventional text should spend a few hours comparing his textbook with its college equivalent. He may be shocked at the tremendous repetitiousness he finds. The college text will usually cover almost precisely the same material, in almost precisely the same order of areas, and with almost precisely the same general treatment. It will be somewhat more quantitatively involved, and that is about the only substantive difference.

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[15] Dean Chamberlin, Enid Chamberlin, Neal Drought, and William Scott, *Did They Succeed in College?* (New York: Harper & Brothers, 1942), pp. 206–213.

Koos[16] made a study of this. He found that the same relative amount of space was given to each topic by the high school books and the college books of chemistry and their manuals. He discovered that 100 per cent of the content of a single high school chemistry manual was contained in one or another of the two college manuals. He concluded that a student who takes high school chemistry and then takes general inorganic chemistry in college repeats almost all of the high school course. Comparable results may be expected if the study were repeated for physics.

The blame for this redundancy should not, of course, be placed entirely on the high school teacher. Few college teachers of science ever bother to determine how much their students already know at the beginning of their courses. The most able students have often been forced into boring, average grooves in beginning college science courses. This has been shown by Jones[17] in his interesting report in the University of Buffalo studies.

The high school teacher can do little about poor college science instruction. But he can face up to these facts in his own instruction. He should not assume that the mere taking of high school physics or chemistry will give the student ability to repeat the same work in college with high success, for this assumption ignores the nature of learning and the fact that the sharp edge of interest has been taken off by the time the student begins his college course. Boredom, if nothing else, will often cause the student to neglect his studies the second time he is run through the mill. The brighter and more creative-minded the student, the more this is apt to be true. And, if a student has been given only superficial "factual" instruction through several years of general science, then in physics, chemistry, and biology, and then repeats the same content in college, he surely has had a surfeit of so-called "science."

Undergraduate college instruction is sometimes poor instruction, particularly for the gifted student. The method is too often rote learning evaluated by questions based on a textbook rather than independent study, group exploration of significant issues and problems, and critical attack from an experimental and reflective point of view. This has been well shown by Seashore,[18] who studied classes which were divided into sections on the basis of ability groupings. He concluded that the low-ability groups were handled better than the groups of superior students (apparently because it was clearer to the college instructors that the low-ability students had to be handled as individuals). The bright college students are often routinely taught from a text at a pace necessary to achieve "coverage."

The high school teacher need not mimic poor college teaching. He can do what

[16] L. V. Koos, *The Junior College* ("Educational Series"; Research Publication No. 5; Minneapolis: University of Minnesota, 1924).

[17] Jones, *op. cit., passim.*

[18] Carl Seashore, *Learning and Living in College* (University of Iowa Studies, First Series, No. 126; Iowa City, Iowa: University of Iowa, 1927).

thousands of good college science teachers are doing—provide the challenge and stimulus of group analysis and independent study for his students that may start some of them on the road to professional work in the field.

We underestimate our students. They want to learn; they want to think; they want to find out and to experiment. The fact that they do not all want to study exactly the same things from the same textbook, at the same time, and in the same way does not make these wants less real. And the facts that are usually presented in the textbooks are surely of no greater importance than the increased power of analysis, ability in critical reading, functional understandings, and critical thinking that we might develop if we could break away from this imagined responsibility to cover the field as presented by our textbooks.

Some Judgments from the Colleges

Before leaving the general subject of college preparation in science, it might be well to sample some of the studies on what the colleges and college science professors think about high school preparatory science. College instructors doubtless vary greatly in their judgment, but it is likely that the majority would consider some sort of high school instruction of value.[19] One study, however, implies the opposite. Wetzel[20] sent a questionnaire to chemistry professors in thirty-eight colleges and universities. His purpose was to learn their opinions about deficiencies in beginning chemistry students. Although 61 per cent of the colleges offered separate courses for students who had a background of high school chemistry, he found that only one-third of the college professors of chemistry preferred students who had taken chemistry in high school. Apparently, they either preferred to start from scratch in the subject or felt that the high schools had generally done so bad a job of instruction that more harm than good had come of it.

That colleges are not today necessarily watch dogs, insisting on a particular form and content for high school science courses, is clearly indicated in a study by Carleton.[21] He had developed a physical-science course at Summit High School in New Jersey that he believed was more profitable for students than the traditional chemistry and physics. He inquired of seventy-eight colleges and universities whether they would accept this course as a college-entrance credit. All seventy-eight responded that they would.

What is needed today is a large group of well-trained and professionally minded science teachers who will modify their teaching techniques on the basis

[19] A. G. Hoff, "The Effect of the Study of High School Chemistry Upon Success in College Chemistry," *Journal of Educational Research*, 40:539–542, 1947.

[20] Junius C. Wetzel, "Deficiencies of Elementary Chemistry Students in College and University" (Master's thesis, University of Colorado, 1938).

[21] Robert H. Carleton, "The Acceptability of Physical Science as a College Entrance Unit," *Science Education*, 30:127–132 (April), 1946.

of modern concepts of education and learning within the framework of sound experimental designs and who will add to our presently sparse data on what is sound science teaching for college preparation. We need accurate reports of the procedures used in experimental teaching and of the results of this teaching on students. We particularly need more information regarding what is effective with the gifted student.

OTHER RESULTS OF CONVENTIONAL SCIENCE TEACHING

Few science teachers today would hold that college preparation is their only, or even their chief, instructional goal. Critical thinking, sound attitudes, useful and functional information, a sound conception of the world and man as science now sees them, an understanding of the nature of science—these are important goals, too. What is the record of conventional teaching when considered against such objectives?

The Retention of Science Learnings

If we teach about a digestive enzyme, Avogadro's hypothesis, or balancing an equation, presumably it is because we want the student to retain the knowledge or skill somewhat longer than would be required to pass an examination on the course. If a student forgets many of the facts he has "learned," if he cannot employ principles, or if his skills rust within a short time, we can question whether the taxpayer and the student are getting a sound return from their financial and time investment in the science teacher.

Over the past fourteen years, at two major universities and one state college, the author has put three simple questions to a total of more than two thousand college students. Most of them were juniors, seniors, or candidates for the master's degree. Science majors were excluded from answering. The questions were put orally to students enrolled in regular college classes.

Before asking the first question, he determined how many students had taken high school chemistry and how many had taken college inorganic chemistry or general chemistry. The first question ran about as follows: "Suppose that you want to run off a batch of oxygen in your basement or apartment tonight. You, who have taken chemistry either in high school or college, or both, have almost certainly prepared oxygen in the laboratory and have learned how to balance equations. How would you proceed to figure out how much potassium permanganate and how much manganese dioxide you would need in order to prepare any given amount of oxygen from these chemicals?"

Unless the reader has forgotten what chemistry he once learned, he will realize that manganese dioxide is but a catalytic agent and the amount is relatively immaterial. He will realize, further, that potassium permanganate and manganese dioxide will not react under typical laboratory conditions to produce oxygen.

Do conventional techniques of instruction result in durable learnings or is the knowledge superficial and retained only long enough for passing the formal paper-and-pencil examinations of the classroom? We underestimate our students. They want to learn; they want to think; they want to find out and to experiment. But conventional "cook-book" substitutions for experimentation under the guise of college preparation can stifle student interest and thwart sound preparation for college work. (Courtesy of Great Neck, New York, Public Schools)

Potassium chlorate is, of course, the chemical typically used in the laboratory production of oxygen. Now, although this is a trick question, it is nonetheless startling that, out of many hundreds of students who have taken high school or college chemistry or both, the author has found to date only three college students who recalled that potassium chlorate rather than potassium permanganate was required. None, so far, has suggested that the amount of manganese dioxide was of no large consequence.

Only slightly better results have been obtained from the other two questions, one in physics and the other in biology.

Any science teacher can do his own informal investigation of retention by a similar method. Any group of adults or students who have been away from a science course for six months or more will be fair game. The results will be

discouraging to the science teacher who has assumed that conventional science teaching has "taken."

There have been a few more formal investigations of the question of retention. In 1930, Johnson[22] reported on a study at the college level in which he found very poor retention of knowledge, as indicated in ability to succeed in achievement tests in botany. The loss of retention after only three months, as determined by achievement tests, was 43.4 per cent! What is the value of teaching facts and finding they have apparently been learned if over 40 per cent of the facts are evidently lost in only three months?

Powers[23] carried out a careful study in 1924 that is the prototype of others in the field of retention. He developed an examination in chemistry and divided it into twelve sections, each designed to test a different skill or ability. The test included items requiring writing the name and chemical composition of chemical substances, writing formulas and equations, items on valences, on numerical problems, and so forth. The exercises on writing equations and on solving numerical problems were of the simplest kind. The test was applied at twenty-six schools, scattered over the United States, and they were given at intervals after students had completed their chemistry courses. Powers found that the median scores of students who took tests in September, after completing their chemistry courses the previous June, dropped two deciles from their June scores. Considerably more loss was found after a year's lapse of time. The loss, particularly in equation writing and similar rather technical areas, was extremely high after a lapse of five years. This last group of students was small, but out of seventeen individuals, one was able to write one equation from a list of ten, and none of the others could write a single one.

Powers wrote the section on science education in the 1950 edition of the *Encyclopedia of Educational Research*. He concluded, relative to this matter of learning and retaining science information, that an over-all judgment, based on many studies, must hold that students in the physical sciences are not learning their subject matter well enough to use it on examinations. As this—the taking of examinations—is a skill that is developed by schools, one must expect that the low retention, as exemplified on examinations, represents an even lower retention of knowledge that would function in nonacademic situations.

The Development of Scientific Attitudes and Critical Thinking

If a hundred science teachers were selected at random and were asked to list their five chief teaching objectives, it is almost certain that every one would include the development of scientific attitudes and critical thinking on their list.

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[22] P. O. Johnson, *Curricular Problems in Science at the College Level* (Minneapolis: University of Minnesota Press, 1930).

[23] S. R. Powers, *A Diagnostic Study of the Subject Matter of High School Chemistry* (Contributions to Education, No. 149; New York: Bureau of Publication, Teachers College, Columbia University, 1924).

How well has conventional science teaching contributed toward the realization of these excellent objectives?

Superstitions are evidences of unscientific attitudes. The person who believes that broken mirrors, black cats, and the number 13 bring bad luck possesses magical and uncritical beliefs. The degree to which science instruction has reduced superstition is therefore one measure of its effectiveness in developing scientific attitudes. In a study of this area, Zapf[24] found that superstitious beliefs decreased slightly but significantly as the length of time students studied science increased.

On the other hand, Zapf[25] found, in an earlier study, that the mere teaching of science did not reduce superstitious beliefs and that only instruction dealing with specific superstitions appeared to be effective in reducing those superstitions.

There is considerable evidence that superstitious beliefs can be greatly reduced through instruction designed precisely for this purpose. But there is little evidence that science teaching, as such, will result in a mind-set antipathetic to superstitions. Yet, conventional science teaching, organized on the basis of an internally logical discipline, has rarely devoted much time or attention to such beliefs.

That young people do go through our schools and science courses retaining many superstitious beliefs has been amply demonstrated. Caldwell and Lundeen[26] found that high school seniors believed in slightly more than 20 per cent of a list of superstitions and that they were apparently affected by about 22 per cent of the superstitious ideas with which they were familiar.

Ter Keurst[27] gave a check list of superstitious beliefs to over five hundred students in grades seven, eight, and nine. His check list contained ninety-two beliefs that had been judged to be of high significance by seven specialists in psychology. As a result of his study, Ter Keurst concluded that belief in superstitions does not decline with advance in grade level (despite the fact that the majority of his respondents were presumably taking or had taken science courses).

If one of the functions of science teaching is to help young people to examine their beliefs critically, then such studies as the foregoing must receive serious attention from science teachers, for they appear to present a failure of conventional science teaching.

Superstitious beliefs represent a tendency on the part of the believer to ignore the question of causation or to accept beliefs without demanding reasonable

[24] Rosalind M. Zapf, "Relationship between Belief in Superstitions and Other Factors," *Journal of Educational Research*, 38:561–579 (April), 1945.

[25] Rosalind M. Zapf, "Superstitious Beliefs," *School Science and Mathematics*, 39:54–62, 1939.

[26] O. W. Caldwell and Gerhard E. Lundeen, "Students' Attitudes Regarding Unfounded Beliefs," *Science Education*, 15:246–266 (May), 1931.

[27] Arthur J. Ter Keurst, "The Acceptance of Superstitious Beliefs among Secondary School Pupils," *Journal of Educational Research*, 32:673–685 (May), 1939.

evidence of their validity. Other aspects of critical thinking and scientific attitudes have also been tested. Oakes[28] examined explanations of natural phenomena from thirty-five college faculty members, all of whom held at least a master's degree, but none of whom had majored in science. All these trained and intelligent teachers had, of course, some background of instruction in natural science. Yet, Oakes found that they showed little evidence of a consciously reflective or logical procedure in analyzing natural phenomena.

Alpern[29] developed tests through which he attempted to determine high school students' abilities to test hypotheses. He found that there was no significant relation between the science courses a student had taken and his ability to select sound procedures to test hypotheses. The degree to which Alpern's instruments were valid and his sample representative is the degree to which his study offers evidence that students have not developed this skill as a result of their science instruction. Unfortunately, there are no comparable studies reported in the literature.

A most revealing study by Lurie,[30] mentioned in Chapter 1, disclosed that the products of our schools are surprisingly liable to decide an issue, not on its merits, but on the basis of the prestige of proponents or opponents. Other studies comparable to Lurie's provide similar data. Such studies do not reflect the conventional science program alone, of course, but they do suggest that there may have been a considerable amount of formal or informal learning of an authoritarian nature. Common observation will disclose that many science teachers, along with teachers in other fields, teach students to accept their statements without asking for evidence or support. Thus is laid a foundation for the student to accept propaganda uncritically.

A study by Davis of high school students and science teachers in Wisconsin disclosed that, although these students had a fairly clear concept of cause and effect relations and were not superstitious, they did not seem to be able to recognize the adequacy of supposed causes in producing given results. Davis stated,[31]

> Many teachers tend to propagandize their material when there is no specific evidence for the statements they make, and teachers do not consciously attempt to develop the characteristics of a scientific attitude. If pupils have acquired these characteristics, it has come about by some process of thinking or experiences outside of the science classroom.

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[28] Mervin E. Oakes, "Explanations of Natural Phenomena by Adults," *Science Education*, 29:137–142 (April, May), 1945; 29:190–201 (October), 1945.

[29] Morris L. Alpern, "The Ability to Test Hypotheses," *Science Education*, 30:220–229 (October), 1946.

[30] W. A. Lurie, "The Measurement of Prestige and Prestige-Suggestibility," *Journal of Social Psychology*, 9:219–225, 1938.

[31] Ira C. Davis, "Measurement of Scientific Attitudes," *Science Education*, 19:117–122, 1935.

The conclusion that any increased power in critical thought processes or in scientific attitudes develops independently of, or possibly despite, science instruction was tested by Downing.[32] He administered a test of scientific thinking to approximately twenty-five hundred students in grades eight through twelve. He found, first, that there was a fairly uniform and gradual increase in abilities from grade to grade. He found, secondly, *that those students who had not studied science* secured higher average scores on the test of scientific thinking than did those who had studied science; juniors and seniors who had not studied science and who achieved average scores that were .4 per cent and 8.9 per cent greater, respectively, than the scores of juniors and seniors who had studied science from two to four years. It was Downing's conclusion that his study gave no evidence that science subjects, as they are conventionally taught, resulted in higher powers of scientific thinking. It is even possible to hypothesize, within the limits of this study, that the procedures in factual learnings in which the teacher and the textbook were assumed to be correct without supporting evidence might have developed an authoritarian viewpoint in the students and thus lessened of critical thinking.

The validity and reliability of the instruments and techniques that have been developed and employed in assaying scientific attitudes and abilities can, and should, be questioned. The degree to which they are valid and reliable is the degree to which studies such as the foregoing have demonstrated that conventional science teaching has not resulted in significant gains in scientific thinking on the part of the students. Whatever the tests and techniques measure, there is considerable evidence that newer practices in science teaching, which emphasize the development of scientific thinking, produce students who are superior to those taught in conventional classes, as measured on these tests and by these techniques. These studies will be reported and analyzed in Chapter 5.

Emotional and Ethical Maturity

The foregoing sections of this chapter have considered the results of conventional science teaching in what might be called the intellectual aspects of maturity. The job of the school, and the responsibility of the science teacher, is to develop young people of intellectual, emotional, and ethical maturity. In terms of college preparation, the retention and use of knowledge, and the habits and practices of mind that are commonly called "scientific-mindedness," what evidence exists appears to cast doubt upon the adequacy of conventional practices. This is a serious indictment, because conventional programs typically emphasize intellectual factors almost to the exclusion of the emotional and ethical aspects of maturity. If conventional programs are seriously defective in producing intellectual maturity, can we expect better results in the development of emotional, social, and ethical maturity? The importance of these factors and their

[32] Elliot R. Downing, "Some Results of a Test on Scientific Thinking," *Science Education,* 20:121 (October), 1936.

inextricable relation to intellectual prowess cannot be denied. There have been several valid studies that have demonstrated personality (emotional and ethical) weaknesses to be heavily responsible not only for failure in personal, family, and social life but also for failure in technical professions. Reynard and others[33] reported an industry-sponsored study of the causes of failure in technical fields. They state, "In a recent survey less than 20 per cent of the technically trained men released from industry left due to lack of technical competence, whereas 80 per cent left because of a deficiency or improper use of strictly personal qualifications."

Another study, of several years duration, was made of failure in technical work. This was a study of about five hundred men who had failed in engineering jobs. It was reported by Bergen, chief draftsman for E. I. DuPont de Nemours and Company and chairman of the committee that made the investigation. The following excerpts from the report reveal the findings in the context of surprise with which the committee reacted to them.[34]

> . . . the results of the study startled us when we made the check analysis. By the time we made the check analysis our faces were somewhat red, because we found that we were paying two dollars for the "psychological and personality" factors for every dollar we paid for the "ability and knowledge" factors on the more responsible jobs. While we had known all along that these psychological factors were important, I think that it can be taken for granted that all of us engaged in the study felt that the academic learning carried far more weight than we subsequently found to be true. . . . As a result of the study, however, we have had to change our thinking radically.
>
> The greatly increased importance attached to the "psychological and personality" factors posed a number of new questions, however. Because of the weight of these factors, it became quite necessary to ask ourselves:
>
> 1. How can we teach co-operation, initiative, creativeness, judgment, common sense, supervisory ability, or leadership?
> 2. What are these psychological factors composed of?
> 3. How are these personality characteristics learned? We are still engaged in trying to find the answers to this disconcerting series of problems.

Although the importance of education for emotional, ethical, and social maturity has been emphasized since the beginning of the American school system,

[33] J. W. Reynard and others, "Employment Opportunities in Chemistry," *Journal of Chemical Education*, 26:62–81 (February), 1949.

[34] Martin John Bergen, "What Industry Requires of the Graduate Engineer: A Case Study," *Journal of Engineering Education*, 40:40–47 (March), 1950.

there are few experimental studies which validly demonstrate either the effectiveness or the lack of effectiveness of conventional school programs as such. This is not surprising, since it is quite clear that the school is but one of many institutions interested in the problem. It is impossible to isolate the influence of the school from that of the home, community, church, and the peer cultures to which children belong.

This is not to say that there have been no experimental studies of character education. There have, and some of them will be reported in Chapter 5. But it can be stated categorically that many typical school practices, including competitive-marking systems, emphasis on individual competition rather than group work, and sarcasm and other forms of censure have created their share of antisocial behavior, feelings of inadequacy and frustration, and the concomitants of cheating, truancy, deceit, and various forms of aggressive behavior. These are hardly the components of emotional and ethical maturity.

SUMMARY

Valid and reliable research data in science education are limited. Such data as are available appear to make conventional practices of science teaching questionable from several points of view. Studies related to college preparation seem to support the hypothesis that increased power of analysis, ability in critical reading and thinking, and independent and reflective thinking are more important than the acquisition of facts for success in college. Studies of the retention of science learnings, generally limited to the retention of specific facts and skills typically tested for on standard examinations, appear to indicate that students, in the physical sciences at least, do not retain their subject-matter knowledge well. This low retention on standard examinations may reflect an even lower retention of knowledge that will function in nonacademic situations. Various studies have shown that conventional science teaching has had little effect in reducing superstitious beliefs and uncritical attitudes or in developing consciously reflective abilities to analyze natural phenomena or to test hypotheses. Emotional and other personality factors are important to success in science careers as well as to daily living. Yet, many conventional practices have negative effects on these factors.

Reflection based upon the studies reported in this chapter suggest that newer practices, which emphasize the development of intellectual, ethical, and emotional maturity are more likely to promote student success in college and in happy and effective daily living, than conventional practices, which are preoccupied with covering a particular science from a content point of view.

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5

THE PSYCHOLOGICAL BASIS OF MODERN SCIENCE TEACHING

Chapter 4 presented data illustrating the fact that a good deal of what is *taught* in science classes today is never really *learned* by the students. What the teacher teaches is one thing. What the student learns may be quite another. Young people quickly forget much of what they were taught in science classes, first, because, from a psychological point of view, they really never learned; and, second, because the facts and principles they were supposed to have learned were never assimilated into functioning relations with their daily lives and were, consequently, inert and unusable.

Long ago, Henry Adams pointed out that "nothing in education is so astounding as the amount of ignorance it accumulates in the form of inert facts."[1] The modern science teacher is not interested in producing walking encyclopedias of factual information that is not used. He knows that the assumption that young people are like reservoirs to be filled with knowledge is based upon ignorance of the nature of the learning process. He teaches in a fashion different from that of many of his predecessors because he has studied what we now know about the nature of learning and he has found that methods different from those commonly used in the past are required if effective learning is to occur and if the behavior of his students is to be changed.

[1] Henry Adams, *The Education of Henry Adams* (Cambridge, Mass.: Riverside Press, 1918), p. 379.

The modern teacher is not uninterested in teaching his students facts and principles. Indeed, it is because of his recognition of the failure of much teaching in the past to develop substantial and usable knowledge of the facts and principles of science that he has modified his practice. He wants students to become informed, to use their knowledge wisely, and to continue to learn long after they have completed their formal education. Unless teachers know how their students learn, they cannot teach with effectiveness or with assurance of sound results.

What is now known about the learning process and what does this knowledge mean for the science teacher? These questions will be explored in this chapter.

THE PURPOSIVE NATURE OF LEARNING

All learning, indeed all behavior, is purposive. The human organism is not like a machine; it is not wound up in the process of birth to go reactively through meaningless processes of behavior and learning until it unwinds and dies. It is not a passive slate upon which learning may be written by a teacher. It is not a reservoir to be filled with knowledge.

A human being is complex. He has hopes, desires, fears, needs, wants, interests, and memories. He does not react to stimuli as does a mechanical contrivance or an electrical system. Flip a light switch and the light will go on; it is as automatic as that. Teach a class Newton's third law of motion and what have you? The learning that for every action there is an equal and opposite reaction? Not at all. Not for every child and not for any one child the same as for any other child, for the backgrounds, moods, and purposes of students will differ tremendously, and their learning and the extent of that learning will vary accordingly.

Let us examine this proposition more closely. A physics class was asked to study the section of their textbook dealing with Newton's third law of motion, and the teacher demonstrated this law through the use of a suspended can, punched with holes at an angle, filled with water, and turning in the opposite direction from the stream of water issuing from the holes. The teacher—who was a good teacher—spent a class period discussing this law and its application with the class. What did the class learn?

We shall examine a typical pupil, a girl named Mary. Mary comes from an upper-middle-class home and is quite intelligent. Her mother went to a good "finishing school" for girls and wants Mary to go to the same school. Mary is attractive, popular, and has a good time; but she does not neglect her studies, which she seems to get with ease. What has Mary learned? On the evidence of a test the teacher gave some two weeks after the instruction, Mary had learned enough to match the statement, "Newton's Third Law of Motion," with another item of the text, "For every action there is an equal and opposite reaction." Furthermore, she accurately solved a simple problem involving this law of

motion expressed in quantitative terms. Mary made her usual A in the test, and the teacher wished that he had more students as able as Mary.

But what had Mary actually learned? For one thing, Mary had for some time been learning to "get by" with little application. "Book learning" came easy to Mary. A few minutes with each lesson assignment and things were under control. The simple expression of Newton's third law of motion was, for her, an easy thing to learn, as were the pencil and paper exercises that the teacher required each student to turn in each day. So her lesson in getting by continued. She was not challenged by her lessons, but this suited her, for Mary never saw any real value in her physics course. Mary's chief source of motivation was to be popular, to have fun, and to get good grades so that she could get into the college of her choice.

There is nothing particularly wrong with all this, except that Mary never learned the generalized truth expressed by Newton's third law of motion, despite the apparent contrary evidence of her test results. She learned a verbalistic statement and the ability to do a few paper and pencil exercises and problems. The teacher falsely assumed that this was a real learning of this law of motion. That it was not a real learning—that it was verbalistic and carried little or no understanding that would function in Mary's life—is shown by the fact that, when an outside consultant suggested repeating the test but changing the form of the items and some of the terms, Mary did quite poorly. The matching item on Newton's third law of motion was changed to the following: "A man weighing 150 pounds stands in an elevator. The elevator suddenly starts up. The man's weight seems to increase by 10 pounds. What, if any, force, in pounds, did the elevator floor exert on the man when the elevator started up?" To the teacher's surprise, many of the better students, including Mary, could not answer the question and apparently did not even understand it. The results of the changed test, in which many such changes as the foregoing were made, were revealing in quite another way. Mary was furious with the teacher and held that the test was unfair. She was quite concerned about her low grade and the fact that some of the students whom she ordinarily outranked considerably in tests, had done better than she had done.

What had been Mary's purposes in the course? It began to look as if Mary had been interested in making good grades, in working just enough to make those good grades on the basis of verbalistic responses, and in maintaining her sense of superiority in the classroom. Was she concerned because the modified test gave evidence that she did not understand many of the concepts involved in the course? Not at all. She was concerned because her main objective—making good grades and feeling superior to other students—had been placed in jeopardy. She was not concerned about the evidence that she really never understood Newton's third law of motion, because real understanding had never been her goal. Understanding, at best, had been a means to an end.

Let us examine the record of other students in this class. Take Jim. Jim

comes from a lower-middle-class home. He carries papers before school in the morning and again after school. On Saturday, he works for a grocery store, and a friend handles his paper route for him. His parents want him to go to college, and Jim would like to go, but his grades are rather poor. Jim has an I.Q. of 128 on the basis of a group test. But Jim suffers from a feeling of inadequacy. He is rather thin, nervous, and tends to overdo. He tries hard to study and to make good grades, and he "crams" for hours before a test. Jim is a quiet boy and, because of his retiring nature and his out-of-school work, has not learned to be at ease with the other students. He has a few close friends, but he is awkward and ill at ease when called on by the teacher to recite in class. Jim does passably well in physics, except for the problems that involve simple algebra and arithmetic. He "goes to pot," as he expresses it, when "mathematics" is involved. Jim made just about the same raw score on the modified test as he did on the test in its original form. But his rank order in the class was elevated considerably. This appeared to please Jim a good deal. He took some pride in the fact that he had realized that "force" was synonymous with "action" and "reaction" in the terms of Newton's third law of motion and that the elevator problem was an application of this principle.

What had Jim been learning in the course? He had been learning more and more to fear competition and to hate himself for his stupidities. He knew that his parents wanted him to go to college and expected great things of him. He had done reasonably well in his school work, but he had always carried the feeling that it was "by the skin of his teeth" that he made his C's and his occasional B's. Jim's purpose had been primarily to show his parents, and above all himself, that he could be a success. Yet, he had been slipping badly in physics and had become quite tense about it.

While the teacher was teaching Newton's third law of motion, Jim was learning increasingly to fear the challenge of competing with others. He was learning to plan explanations ahead of time for his "failure." He was learning to hate school because of his fear of himself. He was learning to believe that he was a "mathematical moron." He was learning to spend hours brooding over page after page of his textbook and was calling it "studying" when it was really daydreaming and worrying. Like Mary, Jim needed the feeling of success and of being popular with his peers. Unlike Mary, Jim had not yet learned how to reach his goals. But Jim was really no more interested in physics in general, and Newton's third law of motion in particular, than was Mary. The learning, for Jim as for Mary, was a means to an end. The only difference was that Mary was realizing her purposes and Jim was not.

Now let us look at Mike. Mike likes to "fool around" with machines. He has an old Ford that he works on endlessly. He is not quite sure why he took physics, but it is probably tied up some way with his interest in mechanics. Mike wanted to learn about machines. Physics has been something of a disappointment to him. He had expected to learn a good deal about automobiles

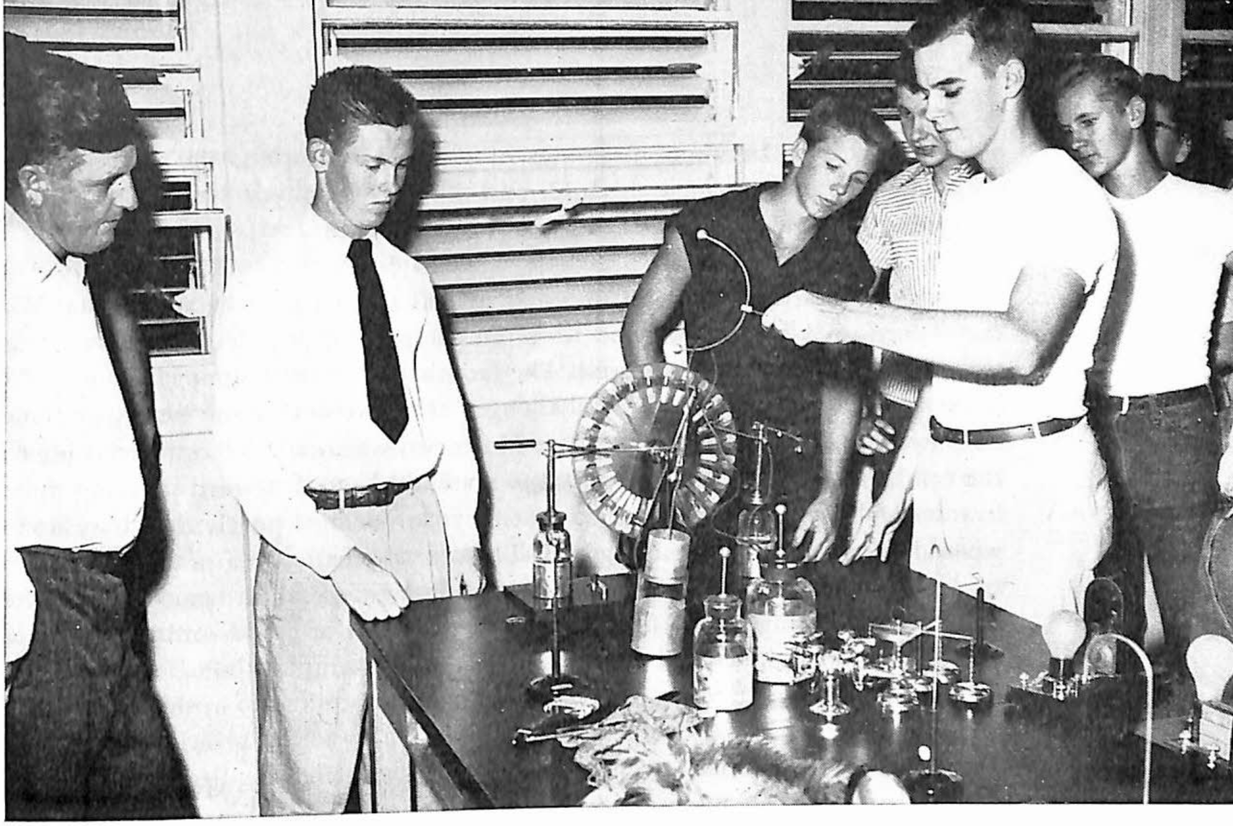
and other machines but, "All you learn is a lot of stuff that doesn't do you any good."

Clearly, Mike was ripe for learning. He would have welcomed even theoretical knowledge that he could apply to his old Ford and to machines in general. But Mike felt a little cheated by the course. Newton's third law of motion? So what? What did that have to do with cars? Mike never quite found out. Perhaps the teacher did not know. Or perhaps the teacher assumed that, if Mike learned what he taught about action-reaction, Mike could easily apply this knowledge to his interest in gears, cams, pistons, carburetion, and all things mechanical. Unfortunately, this was not so. It simply never occurred to Mike that Newton's third law of motion might apply to his interests. So Mike did his best in the course, without particularly studying or trying, of course, and decided that physics was much like the other courses he was taking—just something to take because that was school.

What did Mike learn while the teacher taught the third law of motion. He learned that school is something you endure until you can get out of it. He learned how to get by, as did Mary, but on a lower level of success that satisfied Mike but would not have satisfied Mary. He learned not only to consider school as an annoyance to put up with but, increasingly, as something boring and finally to be hated and ridiculed. If Mike—who thinks he wants to be a mechanic—turns out to be a good mechanic, it will be despite his physics course rather than because of it, for Mike is not learning mechanics in school, although that is what the teacher is teaching. The teaching somehow just does not jibe with Mike's purposes and interests in life.

There are other students in this class. There is the little youngster from "the other side of the tracks" who is poorly dressed, something of a bully, and who does not pretend to study. What is he learning? To resent even more "the jellies," as he calls them, who are nice and polite, who study like darn fools, and who "lick the teacher's boots." There is the little girl with the soulful eyes who stutters occasionally and who seems to be scared to death. There are other young people in the class, too. They are of all sorts, sizes, backgrounds, interests, purposes, and abilities. Most of them are quite "average" youngsters who do not stand out one way or another. The teacher attempted to teach all these young people Newton's third law of motion. In one way or another, most of them learned enough about it to respond to paper and pencil tests with some accuracy. But in no single case is there evidence that real learning about Newton's third law of motion took place. For no single student had quite seen this expression of a generalized truth as important to him, a part of his goals and interests, or of possible direct value to those things that are really important to him.

Many things were learned as the concomitances of the learning experience—but not a real and functioning conception of the relation between force and reaction. A consultant asked the teacher, "Why do you teach this law? What changes do you want this to make in the children, and how will what you teach



What is taught is not necessarily what, or all, that is learned. Concomitant learnings, highly dependent on the complex and varying purposes of the individual pupil, determine what will actually be learned. What learnings will result from this demonstration of static electricity is heavily dependent upon such individual purposes. (Courtesy of Phoenix Public Schools)

make such changes come about?" The teacher was not ready with an answer. It is likely that the children learned the law only as a verbalism, without functional value, because the teacher had learned it in that way, too, and did not see it in terms of the lives and purposes of his students.

CONCOMITANT LEARNINGS

There is a second lesson to be learned from the foregoing classroom situation. We do not have the choice of teaching a simple fact, law, or skill, with no concomitances, or of teaching for a particular pattern of desirable learnings, for concomitant learnings, helpful or harmful, will inevitably proceed. We can only choose between providing the total situation most conducive to the development of wholesome and effective personalities or ignoring the classroom situation, to our students' hurt. We should be particularly careful to avoid practices which create arbitrary hurdles for all our students.

We would not countenance the practice of requiring all students to jump obstacles of an identical height in the athletic field, regardless of their physical

prowess or build. In sound programs of physical education, we work for the optimum development of each child, and we provide physical examinations to determine reasonable goals for individual achievement.

Our common practice in academic work is less sensible. We set arbitrary standards and achievement hurdles and ask all to jump at the same time. We then count as failures those who have not jumped the hurdles and as successes those who have jumped them well. The fact that many who jumped them could have jumped far higher had we challenged them to work more nearly at their optimum should be of concern to us. Moreover, we should be concerned about the results of requiring the less gifted to do what they can toward jumping these hurdles and then marking them so that they can see how poorly they have done when compared with the more gifted. The old saw that such a practice prepares students for the real world of competition is logically absurd and ignores the nature of real competition, for school competition is for grades and symbols, not for real accomplishment. It degenerates very easily into pathological envy and frustration that create a tendency on the part of the student to avoid competition and to employ antisocial detour behaviors to make up for his growing personality lacks. Continued failure produces work of decreasing quality, as has been reported in a minor sphere by Sears.[2] (A fuller account of Sears's study will be given later in this chapter.) Any practicing psychiatrist can add to Sears's data from his own practice. The famous *Studies in Deceit* of Hartshorne and May[3] clearly showed the deceptive behavior indulged in by students who were unable to attain arbitrarily set school goals by direct means. Kvaraceus[4] and Sandin[5] have also studied this phenomenon. The studies of Lewin[6] and of Dollard[7] and their colleagues add to the data. These studies, which have been mentioned in an earlier chapter, show the effects of teacher-dominated classroom procedures in producing frustrations and their many concomitances. Failing students are often unhappy, negatively aggressive, and delinquent. They will cheat, rationalize, and often stop trying altogether if the competition is too intense. They cannot develop into persons who are psychologically secure and well informed. Neither

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[2] R. R. Sears, "Initiation of the Repression Sequence by Experienced Failure," *Journal of Experimental Psychology*, 20:570–580, 1937.

[3] Hugh Hartshorne and M. A. May, *Studies in Deceit* (New York: The Macmillan Company, 1928).

[4] W. C. Kvaraceus, "Delinquency—A By-Product of the School?" *School and Society*, 59:350–351, 1944.

[5] A. A. Sandin, *Social and Emotional Adjustment of Regularly Promoted and Non-Promoted Pupils* ("Child Development Series," No. 32; New York: Bureau of Publications, Teachers College, Columbia University, 1944).

[6] Kurt Lewin and others, *Authority and Frustration* (Studies in Topological and Vector Psychology, Vol. III; Iowa City, Iowa: University of Iowa Press, 1944).

[7] John Dollard and others, *Frustration and Aggression* (New Haven, Conn.: Yale University Press, 1939).

security nor optimum knowledge can result from practice based on arbitrary standards of accomplishment for all.

Any unit of instruction and any single class hour of instruction is pregnant with possibilities for the development of sounder personalities of higher stature. Curiosity, drive, responsibility, effective communication skills, critical-mindedness, good citizenship, feelings of belonging and being liked, personal security—all these are affected positively or negatively every instructional hour of the day for better or for worse. We have seen that these traits are often negatively affected. We know that they can be positively affected. The studies of Wrightstone,[8] Morgan and Ojemann,[9] Jersild,[10] Blair and Goodson,[11] Kilgore,[12] Arnold,[13] and Weisman,[14] among many others, disclose the kind of classroom and environment that is conducive to the positive development of these qualities. A teacher can ignore his responsibility to his students and to society and "teach his science." But his science will be less well taught, less well learned, and his higher function as a representative of both democracy and science will have been subverted.

THE MYTH THAT DISAGREEABLE TASKS ARE THE MOST EDUCATIVE

No concept of education held by responsible people ever proposed that children should be allowed to do just what they want to do, at the time they want to do it, and nothing else. But there has existed a "child-centered" philosophy of education which is based upon the observable fact that real and durable learnings, contrasted with verbalistic learnings, come from experiences which the child develops out of his own purposes.

Representing the opposite philosophy is the schoolroom in which children are expected to learn, under duress, whatever the teacher cares to teach, without regard to their backgrounds, interests, and purposes. This conception needs no

[8] J. W. Wrightstone, "Evaluation of the Experiment with the Activity Program in the New York City Elementary Schools," *Journal of Educational Research*, 38:252–257, 1944.

[9] M. I. Morgan and R. H. Ojemann, "The Effect of a Learning Program Designed to Assist Youth in an Understanding of Behavior and Its Development," *Child Development*, 13:181–194, 1942.

[10] A. T. Jersild and others, "An Evaluation of Aspects of the Activity Program in the New York City Public Elementary Schools," *Journal of Experimental Education*, 8:166–207, 1939.

[11] Glenn M. Blair and Max R. Goodson, "Development of Scientific Thinking through General Science," *School Review*, 47:695–701 (November), 1939.

[12] William A. Kilgore, *Identification of Ability to Apply Principles of Physics* (New York: Columbia University Contributions to Education No. 840, 1941).

[13] Dwight L. Arnold, "Testing Ability to Use Data in the Fifth and Sixth Grade," *Educational Research Bulletin*, 17:255–259, 278 (December), 1938.

[14] Leah L. Weisman, *Some Factors Related to the Ability to Interpret Data in Biological Science* (Chicago: University of Chicago Press, 1946).

caricaturing. It is pretty much what is still done in many science classrooms throughout the United States today. It is one of the residuums from the past, and represents, in part, a reflection of the old and now discredited notion that the child is by nature depraved and that education must coerce him into salvation of his educable faculties. But, primarily, it results from ignorance of what is now known about the learner and the learning process.

The idea that a child must be forced to learn—that he will learn only reluctantly and under coercion—is by no means to be found only in histories of education. In one form or another, it exists today in the minds of many teachers and parents. As a matter of fact, thousands of teachers, including science teachers, appear to believe that young people must be required to perform disagreeable and difficult tasks without seeing their meaning, precisely because this is "preparation for real life."

"The children are lazy—they won't work unless I stand right over them with a whip." "How can you get children to study? They seem to think that life will always let them get by." "Young people are going to have to learn that life is no bed of roses. I make them learn what is good for them whether they like it or not. When they get out into the world they will thank me for it." These are common expressions of the point of view that children are lazy and that the proper job of the school is to force them to "learn" if for no other reason than this will prepare them for the life of the world outside the classroom, where one is forced to do things "whether he likes it or not."

This viewpoint is downright absurd, and dangerously so. It has created more distaste for school and learning and more blockages in the learning process than any other single notion held by teachers. In the first place, children are not "by nature" lazy. They are reluctant to assume disagreeable tasks, as are we all. But when they do something for reasons that they have accepted emotionally and intellectually as worth the candle, they will work with amazing fortitude.

The notion that life requires one to do many things under coercion and without knowing the reasons for the work is particularly silly. Only slaves and the inmates of penal institutions and some schools are subject to such necessity. Of course, a man will work long hours and drive himself to accomplish certain tasks. But he does so of his own free volition. He may do so because he has to earn a living. He may perform grueling and highly distasteful tasks because he is earning the family bread. *But he sees the connection between his disagreeable task and his goal of earning a living.* No outside authority is forcing him to continue at that particular job. He is not blindly following the dictates of some unseen authority or a taskmaster. He knows why he is doing his work, and this motivation keeps him at it.

Moreover, few men would stay at a job which was distasteful if they knew how to move to a better one. Men who are really happy and successful work at jobs which they like and in which they find the satisfactions of good workmanship and success. Scientists and other professional men are notoriously hard

workers, sometimes working the clock around. They do so, not because someone is cracking a whip over their heads, but because they want to—because they have accepted the purpose of the work and are gaining rich satisfactions from doing it.

We repeat: Only slaves and the inmates of prisons and certain educational institutions are forced to do things blindly, without personal purpose, and only because of extrinsic punishments and rewards. We are not interested in preparing youngsters for subservience and docility. We are interested in developing young people of high character, self-direction, skill, and intelligence. Yet, the literature of educational research is replete with evidence of the negative effects of the "do-it-or-else" philosophy of education. Maslow and Mittelman[15] have shown that coercive education destroys self-direction and self-reliance in students. The work of Lewin, Lippitt, and White[16] shows how differently the personality reacts to purposive learnings and to meaningless, distasteful, coercive learning situations. The latter is disintegrative to the personality and may result in neuroticism and all sorts of aggressive, antisocial behaviors.

There are many other studies which show the same results. The interested reader should check the literature of psychology, psychiatry, and education on these points. Further elaboration is beyond the scope of this volume, but the reader's attention is called particularly to the references below. Dollard's study[17] presents the thesis that aggressiveness is the inevitable result of frustration. The other references[18] bear on the same problem and present corroborative data.

These criticisms of coercive learning situations do not mean that the science teacher should let his students do just what they want, when they want, and nothing but what they want. Nor do they imply that science programs should be shapeless and without organization. They do suggest that profitable learning experiences in science will result only when young people are brought to understand the importance of the proposed learnings.

There is a path between that taken by the proponents of the "child-centered" school and the adherents of the formal, disciplined "let-there-be-no-nonsense" subject curriculum. This is the path taken by the proponents of the newer science programs described briefly in Chaper 1. Teachers of these newer programs

[15] A. H. Maslow and B. Mittelman, *Principles of Abnormal Psychology* (New York: Harper & Brothers, 1941).

[16] Kurt Lewin, Ronald Lippitt, and R. K. White, "Patterns of Aggressive Behavior in Experimentally Created Social Climates," *Journal of Social Psychology*, 10:271–299 (May), 1939.

[17] John Dollard and others, *op. cit.*

[18] N. E. Miller and others, 'The Frustration Aggression Hypothesis," *Psychological Review*, 48:337–342, 1941; Gardner Murphy and others, *Experimental Social Psychology* (rev. ed.; New York: Harper & Brothers, 1937; Stansfeld Sargent, "Effects of Difficulty Level upon the Thinking Process," *Psychological Bulletin*, 37:568 (October), 1940; Pauline S. Sears, "Levels of Aspiration in Academically Successful and Unsuccessful School Children," *Journal of Abnormal and Social Psychology*, 35:498–536, 1940; A. A. Sandin, *op. cit.*; G. E. Carrothers, "Why Do High School Pupils Fail?" *Bulletin*, NASSP, 30:29–36, 1946.

The average student does not enter school with a concern about conservation. But he can be brought to accept the importance of the problem emotionally and intellectually. Until this has been done, attempts at teaching conservation-mindedness and the facts of natural-resource management are doomed to failure. (Courtesy of Atlanta Public Schools)

recognize the fallacy of basing an entire program upon the immediate "felt needs" of youth. These needs are important, and they are considered in developing the science program. But they are limited in that they are the result of experiences young people have already had and necessarily ignore larger questions of social importance.

The average high school youngster, for example, does not come to school with a strong interest in the conservation of natural resources. He is likely to be blissfully unaware of the gravity of the problem of maintaining our top soil. For the teacher to leave him in his immature state of lack of interest is educationally indefensible and psychologically unnecessary, for the problem is real, and the child can be brought to accept its importance emotionally and intellectually. This has been proved time after time in science classrooms throughout the nation. Young people want to learn. They like to have their eyes opened to larger vistas. They enjoy working on tough problems, and they work on them assiduously if given the chance and intelligent supervision.

But young people have to *see* the problem or the desirability of the learning.

There is quite a difference between insisting that young people learn this or that, because you, as a mature adult, know that it is good for them to learn these things, and, on the other hand, helping young people to see the importance of a problem or a specific learning. The first is likely to lead to sterile learnings, to create distaste for science, and to foster aggressive attitudes, and habits of "getting by." The second can lead to learnings that are intensive, critical, continuing, and developmental. It is the latter learnings that we are after.

THE TRANSFER OF LEARNINGS FROM THE CLASSROOM INTO LIFE SITUATIONS

Even the most fundamental science facts and principles will be learned verbalistically and will not affect the student's behavior materially, unless the student has an insight into the proposed learning and establishes that learning as a goal he really wants to reach. If the learning is seen by the student as of importance only to secure a grade or to achieve status with his parents, the teacher, or his peers, he will doubtless attempt to learn what is required to achieve these goals. But it is only when the student accepts the goal emotionally and intellectually as worth his time and effort because of its intrinsic importance to him that learnings will be durable and affect his behavior.

We teach facts, laws, and principles in science, presumably so that our students' lives will be affected in certain desirable ways. We are not really interested in whether the student can answer questions on an examination. We employ examinations with the comfortable hope that they are valid as indications of whether or not our students have developed understandings and abilities that they might transfer to their lives out of school and in later years. The comparative ease with which the majority of students achieve a certain ability to respond to our examination questions sometimes fools us into believing that they have acquired real and abiding learnings. That they often have not is apparent to one who will bother to check the information, attitudes, skills, and behavior of the graduates of our schools.

The author made such a check during the course of World War II. His responsibilities in a branch of the War Department led him to give certain pencil and paper tests to a group of soldiers at a Signal Corps replacement training camp and to compare the results with performances of a more practical order. A group of young men, all of whom had had high school physics, were given test items involving Ohm's law. It was found that most of the men could do a fair job of finding what E was when I and R were given numerical terms in the equation E equals IR. Many had difficulty in clearing the equation and finding what I was when both E and R were given. But, all in all, they showed a certain mastery in responding in writing to questions involving Ohm's law. Most of these men had taken their high school physics courses within a period of a few months to two years preceding the time of the test.

When these same young men were given a practical situation involving Ohm's law, the majority were unable to cope with it adequately. They were taken out to an Army truck which was loaded with field telephonic equipment. The truck had generators which were capable of producing a certain known voltage. The telephones required a certain known current to operate satisfactorily. The spools of wire on the truck had a known resistance per unit of length. The problem was how far the front lines could be moved from the field headquarters and still maintain telephonic communications. Many of the boys who had had no particular difficulty in solving a paper and pencil problem involving Ohm's law did not even recognize this problem as an application of the principle. Relatively few were able to work out the answer.

Why was this? What caused the group of boys apparently to learn a principle, according to the criteria of one sort of test, and yet to be unable to apply that learning to a different but quite simple and relevant situation?

The Nature of Generalization

Ohm's law is not a fact. It is a generalized statement of the relations that always obtain, within limits, between the electromotive force or voltage pushing a current along a conductor, the resistance offered to that current flow by the conductor, and the current itself. Yet, it is often taught in such a fashion that it is learned as if it were a fact. When learned as a fact, it can be used only in the way in which it was learned. If teachers teach Ohm's law as a textbook fact, employ a Wheatstone Bridge demonstration for visual impact, and then test to determine if their students can handle the relations in a simple paper and pencil exercise, their students will usually learn only a verbalism. Students taught in this fashion will not generally be able to apply Ohm's law to various situations where it functions, simply because they never learned the principle, *as a principle,* in the first place.

A principle or generalization, by definition, is what one generalizes out of concrete reality. One learns to see the "chairness" in chairs. When he has developed this generalized insight, he sees the "chairness" of a tremendous range of objects that differ radically in form and structure. A modern Eames chair or a canvas suspension chair differs greatly from a Chippendale chair or an Aztec stone throne. Yet one has no difficulty sensing that each is a chair. One knows what they can be used for, and the differences in design cause no trouble at all in recognizing them and knowing their proper use.

Even very small children generalize out of their experience. A one-year-old became interested in the family Christmas tree and, to the great delight of his family, began to announce, "Tree! Tree! Tree!" His family assumed he must be at least a genius to develop this perception and word usage at so tender an age. For the next few days the parents pointed out other trees to the child and noted with pride that he properly called out "tree" when he saw a tree. A few days later, the child picked up a small dead branch from the edge of the yard and

walked proudly to his father crying, "Tree, Daddy, tree." He had seen the "tree-ness" in a branch. He had begun to generalize out of his rather limited experience. The fact that his generalization was inaccurate from a technical point of view is beside the point. Able scientists, too, often overgeneralize. The point is that the child, just like a scientist, observed many concrete examples, noted certain salient characteristics, and formed certain insights that enabled him to detect these characteristics in a novel situation.

The very nature of a generalization, principle, or law is such that it must be learned chiefly by an inductive process. It requires experiences with reality; words alone, or a simple "experiment" or demonstration alone, will not suffice. A generalization such as Ohm's law requires—if the student is to develop a real understanding of the relations obtaining—that repeated experiences be provided which illustrate the operation of the principle in concrete and realistic situations. Only in this way can we expect that the student will be able to sense the relevance of the principle to new situations. Only in this way can we expect that the student will understand principles and that the understanding will modify his behavior in out-of-school life.

Learnings *are* transferable. That learnings carry over best when the learner has developed generalized insights has been demonstrated repeatedly through investigation. One of the earliest of these investigations was that of Judd,[19] who showed experimentally that the learning of meaningful general principles permitted a more effective transfer than did learnings of facts and habits without benefit of generalized insight and an understanding of principles. One of his studies required young people to hit targets under water. Judd had arranged the target at a depth of 4 inches under the surface of the water. One group of students was given instruction designed to develop an insight into the principle of refraction. The other group were not given instruction on the nature of refraction. Both groups achieved a certain mastery in hitting the target at the depth of 4 inches. The target was then lowered to 12 inches beneath the surface. The students who had learned to hit the target at a 4-inch depth by a process of trial and error were unable to adapt their procedure. The group that had developed an understanding of light refraction (had a meaningful grasp of the principles involved) quickly adapted their technique to the modified situation.

Other studies have shown substantially the same results. When generalizations are actually learned *as generalizations* rather than as verbalistic statements only, the learner is usually able to apply his learnings in new situations where the generalizations apply. An interesting study was made by Bond,[20] who found that a course which emphasized generalizations about racial characteristics reduced superstitions and resulted in changed attitudes about various groups of people, including Jews, Italians, Latin Americans, and Orientals.

[19] C. H. Judd, "The Relation of Special Training to General Intelligence," *Educational Research*, 36:28–42, 1908.

[20] A. D. Bond, *An Experiment in the Teaching of Genetics* (New York: Bureau of Publications, Teachers College, Columbia University, 1940).

School experiences should be such that they lead not only to command of facts but also to the inductive development of generalized understandings which will be retained and used out of the academic climate of the classroom. Can facts, laws, and principles be applied to new problems and situations? This is the clue to the effectiveness of science instruction. (Courtesy of San Diego County Schools)

It is clear from such studies that the science teacher should provide inductive experiences which will create in his students a growing understanding of the generalizations and principles of science that are important in their lives, for generalizations, if meaningfully developed, help one to understand varied natural phenomena and to control one's environment and to predict the consequences of certain actions. It is important, therefore, that science teachers provide experiences leading to generalized understandings and that they avoid the temptation to deal too exclusively with facts, however significant the facts may appear to be. Specific facts are, of course, important. But if taught in isolation or without reference to the student's purposes and background, they can hardly be expected to be long retained or to be used out of the academic climate of the classroom.

Major Steps in Teaching Science for Transfer to Out-of-School Situations

Psychological investigations and the experience of good teachers of science point to certain steps that are of great importance in providing learning experiences of transfer value. They are as follows:

1. The student should understand the possibility of transfer. Unless he is given help in seeing how what he is learning relates to his life and interests and how it will help him in his daily life he cannot be expected to utilize his science learnings outside the classroom.
2. The teacher should search for a variety of lifelike applications that will be understandable and real to the student. If the student understands the usefulness of the learning *to him,* the chances that he will use the learning when the opportunity arises later in life is greatly enhanced. It is important that classroom work be based as fully as possible on lifelike situations, experiences, and materials.
3. It is of particular importance that science teaching be organized in such a way that the learning experiences are inductive approaches to major generalizations and principles. Out of realistic and concrete experiences the student should be led to an explicit understanding of the principles involved. Science is often taught as a stream of facts on an even plane. If the knowledge is expected to function in a student's life, the facts should be taught in such a fashion as to give growing awareness of the basic principles they illustrate. It is possible to teach the facts of a four-cycle engine so that a student knows the nature of such an engine but is hopelessly lost when asked to interpret the nature of a two-cycle engine. It is possible, on the other hand, to teach about the four-cycle engine in such a fashion that students will be skillful in considering the operation of a two-cycle engine without specific and explicit instruction. A student's generalized ability reflects good science teaching.
4. The inductive approach leading to generalized insights should be followed with as many opportunities for the student to apply the principles deductively to as many situations he has not yet encountered as time and the importance of the generalization allow. The degree of learning achieved will be represented by the facility and insight he shows in applying his learning to novel situations. This is an essential stage in teaching for transfer ability. It cannot be expected that students will necessarily recognize new situations as special cases of the application of generalizations and principles unless they are given some assistance precisely in this recognition process. Once they have been given help they can be expected to gain in facility at recognition. It is important that the teacher provide opportunities for students to practice applying generalizations in situations that are sufficiently different from those in which the generalizations were taught that the student cannot readily detect the new situation as another

exemplification of the older learning. This can be achieved, in part, by providing such situations over a period of time well interspersed with learnings of totally different areas and topics.

5. Finally, it is desirable that the teacher evaluate his students' ability in applying generalizations and that he provide additional learning experiences, if necessary, until his students give evidence that they have acquired the generalized insights believed to be desirable. It must be emphasized that a student's ability to state a law or principle is no evidence of real learning. The only valid evidence is the student's ability to apply the generalization to situations comparable to those he may be expected to encounter in his life. If he cannot make these applications it may safely be assumed that he has not developed the necessary understanding, regardless of his power of factual recall or of verbalistic expression regarding the principle.

THE PROBLEM OF MOTIVATION IN SCIENCE TEACHING

Learning can be done only by the learner. The teacher can do no more than stimulate the will to learn and provide the situation in which learning can proceed with efficiency and assurance of lasting value.

One of the chief tasks of the science teacher is that of motivating his students to want to learn. Unless this is done learning will not take place. A preceding section of this chapter attempted to make clear that all learning is purposive. The student's purpose in learning may be different from the teacher's purpose in teaching, but, if learning is to take place, the student must have the purpose to learn. The question of what sorts of purposes are most desirable and effective concerns us now.

Students can be motivated to learn through fear of failure and ridicule, or through other forms of punishment. They can be motivated to learn through praise, good grades, or through other forms of reward. They can be motivated to learn through the sheer showmanship of the science teacher who employs, with dramatic effect, demonstrations, movies, and other devices. They can be motivated to learn through self-activity, challenging lectures, projects, and other teaching devices. And they can be motivated to learn through an insight into the real worth of the learning. All these things and more can motivate students to learn. But the learnings will differ, and the efficiency and permanence of the learnings will differ.

It is theoretically possible for a teacher to teach for a period of two weeks with such showmanship that the students will, without exception, be enthralled, delighted, and anxious for more of the same. But it is also possible, from a

theoretical point of view, to do this in such a way and on such subject matter that the worth, to the students, is considerably less than would be the worth of an equal amount of time spent at local motion-picture theaters—at a considerable saving of the taxpayers' money. Good teaching should not be confused with showmanship. This is one of the dangers that the science teacher should guard against. Surely, no science class should be dull and uninteresting, for the science teacher is dealing with natural phenomena; and its excitement, drama, and power is such that he is, indeed, inept if his students do not catch some of his own enthusiasm for the subject. But, again, this should not allow the teacher to assume that he is a master teacher just because he holds the interest of his class. He is a master teacher to the extent that he has developed sound goals and objectives for his instruction and to the extent that he realizes these goals through his teaching.

Motivation techniques must be closely identified with a teacher's goals. We too seldom think carefully through what we teach for. As a consequence we too seldom vary our techniques of instruction to make them appropriate for our particular goals. If we are anxious to motivate our students toward the beauty of living things or natural phenomena, we should teach in such ways that they come to share our sense of beauty. Aesthetic appreciations can hardly be developed with a heavy hand and a penalty for failure. They require different techniques of motivation than are required for the development of problem-solving abilities or factual understanding.

The Place of Awards and Punishment

Awards and punishments can serve as motivating techniques. They are important tools for the teacher, as has been shown by repeated research. In 1925, Hurlock[21] reported a study designed to determine the relative effects of praise and reproof on learning. Hurlock's study equated two groups on the basis of intelligence and ability and attempted to determine whether the group that was praised learned better than the group that was reproved. She found that both praise and reproof were superior, as a motivating device, to being ignored, and she concluded that consistent praise was superior to consistent reproof as an incentive to learning.

Some years later, another investigator[22] found that blame was slightly more effective than praise as an incentive to learning, under the conditions of his study. Other studies have variously shown that both praise and blame are effec-

[21] Elizabeth B. Hurlock, "An Evaluation of Certain Incentives Used in School Work," *Journal of Educational Psychology*, 16, No. 3:145–159 (March), 1925.

[22] Benjamin Brenner, *Effect of Immediate and Delayed Praise and Blame upon Learning and Recall* (Contributions to Education No. 620; New York: Bureau of Publications, Teachers College, Columbia University, 1934).

tive in increasing learning. Schmidt[23] reviewed these studies in 1941 and concluded that there is no evidence to support either blame or praise as being superior as an incentive to learning, and that much depended upon the total social and experimental conditions. It should be noted that most, if not all, of these studies determined the results of praise and blame on factual learnings and on specific skills and ignored the larger questions of the effects of such motivation on the attitudes, interests, and larger concerns of the students.

Some of the larger and more pervasive effects of failure (a form of reproof or blame) were demonstrated in an interesting study by Sears.[24] He required a group to sort playing cards into four piles according to the suit of the cards. He measured the time required by each individual. Instead of reporting the true time, he intentionally misrepresented the time required so that half of the group experienced constant failure and half of the group experienced constant success. Sears reported that the failure group developed a real sense of failure, and the success group had a sense of real success. He found that the group that was caused to fail repeatedly in any given day slowed down with each successive trial. Their failure apparently caused them to do more poorly as time went on. The success group steadily increased in speed throughout the time of the experiment and developed a distinct superiority over the failure group.

This study, like the preceding ones reported, must be considered with caution. Individuals vary widely. There is considerable evidence that a rather slow child who is constantly competing with students superior to himself will develop a sense of failure that will cause him to do poorer and poorer work and, perhaps, eventually, to cease to try altogether. The bright student, on the other hand, may be motivated to do harder and better work through occasional failure and other forms of blame.

Praise and blame, in various forms, have their place as motivating devices. But they must be used thoughtfully and with care. Blame, particularly, unless applied sparingly and cautiously, may create a distaste for science and a feeling on the part of a student that he cannot succeed. The very fact that he feels this way may doom him to actual failure. There are more usable techniques of motivation for the science teacher.

Effective Motivation of Science Students

If the science teacher is honest with himself and his students, he should have little trouble in motivating his students. If he attempts to teach material that has no clear usefulness or relevance to his students' lives, he will be forced to use the extrinsic motivations of grades and the threat of failure to carry his students along. But, if the teacher knows that what he proposes to teach is of real importance and potential interest to his students, and if he spends the time neces-

[23] H. O. Schmidt, *The Effects of Praise and Blame as Incentives to Learning*, *Psychological Monographs*, Vol. 53, No. 3, 1941.

[24] Sears, *loc. cit.*

sary to communicate his interest and enthusiasm to his students, he should have little difficulty in motivating them to learn.

The chief difficulties science teachers have in motivating students are either that they attempt to teach material that simply is not of worth to their students or that they neglect to help their students share their insight into its importance. Either is fatal to effective learning. If something is worth teaching at all, it is worth teaching in such a way that the students share the teacher's recognition of its worth. If the teacher cannot honestly and clearly see the worth of the material to be taught, he can hardly expect the students to give more than grudging attention to it.

Sound motivation consists essentially in this process of communicating to students a sense of the real worth *to them* of the learning experiences being proposed. To short-circuit this stage in teaching is to make extrinsic motivation necessary and real learnings difficult to attain. Far too little time is taken by most science teachers in this stage of intrinsically motivating students. The teacher sees the worth of his subject and assumes that the students will see it also. This is fatal to a good learning situation, for unless students *want* to learn they will not learn in any real, usable, and durable sense of the term.

THE PLACE OF EXPERIENCES IN SCIENCE LEARNINGS

"One learns by doing" may be an educational cliché, but it is also a valid principle. No one doubts the expression when it is applied to learning a physical skill, such as bicycle riding. It is quite clear that reading of dozens of books, watching demonstrations of good riding practice, and listening to lectures on the art of balance will do little to develop a student's ability to ride a bicycle. One learns to ride by riding. One learns to swim by swimming. The teacher's proper function is to assist the learner to acquire certain useful skills involved and, once the learner has caught the "feel" of the art, to help him sharpen his skill and overcome any bad practices he might engage in before they become ingrained habits.

"One learns by doing" is as valid when applied to academic instruction as when applied to instruction in physical skills. Yet, this fact escapes some teachers of science. Why is it more easily seen as applicable to physical skills? Primarily because of the differences in techniques and instruments used in evaluating physical skills and those used in academic areas. The swimming coach does not make the mistake of discussing the principles of swimming with his students, exploring the technique of the Australian crawl, and then evaluating their ability to swim by means of paper and pencil tests. He does not consider it sufficient for them to analyze these principles and techniques. He knows it is relatively meaningless to discover how capable they are of recalling the facts of leg position relative to arm position at each stage of a properly executed stroke.

If the coach were to test in this fashion, he would find that his more verbalistic-minded students might make a perfect score on his pencil and paper tests. He would find that his less academically gifted students would score rather low on his test. If the ability to score well on such a test were thought to be the proper goal of instruction, the coach would doubtless spend more and more time teaching his students the theory and practice of swimming while the pupils were sitting in the classroom or "boning up" on textbooks devoted to the swimming art.

He knows, however, that the ability of students to pass a paper and pencil test is no index whatsoever of their ability to swim. When placed in the practical situation of attempting to swim, the student who failed the test might exceed considerably in actual skill the student who made an A. Learning to analyze the theory and practice of swimming can be of assistance in improving a student's swimming skill, but it must be based upon some experience in swimming, and the latter must precede the former for the analysis to be of much profit to the learner.

It is a common error for science teachers to assume that a student's ability to make a good score on an objective test of science facts and principles is adequate evidence that the student has learned the science. The question, of course, is what is meant by "learning science." We know what is meant by the expression "learning to swim." We are unsure about "learning science." If the teacher has taught the science as an intellectual exercise in reading and listening, the student will have learned to read and to listen. If the teacher has taught for recall of facts, the student will have learned to recall certain facts when asked for them on a test. Whether or not the student understands the meaning of the facts, whether or not he is capable of using those facts, and whether or not he has changed his attitudes and behaviors so as to adjust to the facts as they relate to his purposes and interests, is another matter.

One learns by doing. If the science teacher wants to improve the quality of his students' approach to problems he must provide them with problem situations and help them to locate the problems, define and delimit them, set them up so that they can be attacked efficiently, and assist the students in working out sound solutions. Critical thinking cannot be expected to emerge from science programs in which the students get no experience in critical thinking. Although critical thinking (more commonly expressed by science teachers as "scientific attitudes and habits of thought") is one of the almost universal goals of science teachers, there is considerable evidence that the average science program has done little or nothing to develop it. This is supported by many studies which illustrate that scientific thinking is not necessarily a by-product of the study of science. Although the instruments of evaluation used are of questionable validity, these investigations present rather conclusive support for this hypothesis about the development of scientific thinking. In one such study the investigator[25] gave

[25] Elliot R. Downing, "Does Science Teach Thinking?" *Science Education,* 17:87–97 (April), 1933; and "Some Results of a Test on Scientific Thinking," *Science Education,* 20:121–128 (October), 1936.

If the teacher wants to improve his students' ability to deal intelligently with problems, he must provide problem situations, carefully set up so that the problems may be defined and properly attacked. He should assist the students in working out sound solutions. Such procedures lie behind the experimentation of these girls in tuberculosis research. (Courtesy of Atlanta Public Schools)

a test of scientific thinking to approximately twenty-five hundred students in grades eight through twelve. He paired students who had taken science courses with students who had not. He found that there was a fairly uniform and gradual increase in the percentage of correct responses from grade to grade but that the students who had not studied science secured higher average scores on the test than the scores of those who had studied science. Juniors and seniors who had not studied science achieved average scores on the test which were .4 per cent and 8.9 per cent greater, respectively, than those of corresponding groups of juniors and seniors who had studied science for from two to four years.

Experiences in Scientific-Mindedness

As was indicated in Chapter 4, Zapf[26] found that the mere teaching of organized science had no effect on reducing superstitions but that instruction that dealt specifically with superstitious beliefs and analyzed them did reduce them. Clearly, from grounds of logic, learning theory, and experimental evidence, it is

[26] Rosalind M. Zapf, "Superstitious Beliefs," *School Science and Mathematics,* 39:54–62, 1939.

unwarranted to assume that the mere study of science will result in critical- or scientific-mindedness. One learns critical thinking only through the process of critical thinking. Thousands of science teachers today continue to hold scientific-mindedness as one of their chief objectives but, in their race over facts, give little or no opportunity for their students to develop this complex skill through practice.

That teachers of science can help their students to be more critical in their thinking and less subject to superstitious beliefs has also been amply demonstrated through other investigations. Caldwell and Lundeen[27] have conducted a number of studies that illustrate this fact. They developed special units in science designed to correct unfounded beliefs about predictions of the future, the weather, and so forth. The units were used in many schools, and it was shown through pretesting and posttesting that superstitious beliefs were reduced by as much as 50 per cent during the course of one school year.

Another investigator[28] prepared a six-week unit on superstitions, based upon Caldwell and Lundeen's list of unfounded beliefs, and taught this unit to 135 students enrolled in general-science courses. Comparison of the results of pretesting and posttesting confirmed the conclusions reached by Caldwell and Lundeen that unfounded beliefs, including superstitions, can be materially reduced through instruction explicitly designed to give experience to students on superstitions. Other investigators, Zapf, Salt, Weller, and Maller, for example, have found similar results.

Another interesting study was made by Arnold,[29] who established control and experimental groups of fifth- and sixth-grade pupils. He employed a "problem-discussion" technique with the experimental group and found that, in terms of average growth, the experimental group in three months of learning to use scientific thinking achieved abilities that would have taken nine months with the conventional instruction.

Experiences in the Application of Principles

Babitz and Keys[30] matched eight chemistry classes and provided "direct and intensive instruction" on the application of principles to the experimental groups, while providing conventional methods of instruction in the control groups. Tests were given that required the students to solve chemistry problems involving the application of principles and to identify the principles involved.

[27] O. W. Caldwell and Gerhard E. Lundeen, *Do You Believe It?* (New York: Doubleday & Company, Inc., 1934).

[28] O. U. Vicklund, "The Elimination of Superstitions in Junior High School Science," *Science Education*, 24:93–99 (February), 1940.

[29] Dwight L. Arnold, "Testing Ability to Use Data in the Fifth and Sixth Grade," *Educational Research Bulletin*, 17:255–259 (December), 1938.

[30] Milton Babitz and Noel Keys, "An Experiment in Teaching Pupils to Apply Scientific Principles," *Science Education*, 23:367–370 (December), 1939.

Every experimental group showed superiority to the control groups of the same school, although the results were not statistically significant. It would appear from this study and comparable ones that the ability to apply principles is best learned through experiencing the thing to be learned.

A study[31] of 120 physics students paired according to I.Q.'s, previous science courses studied, and comparable teachers disclosed that both low- and high-ability students were significantly better in making applications of principles when their course had emphasized applications.

A doctoral study conducted by Barnard[32] involved working with college students enrolled in two introductory courses in biology. In one course, the conventional lecture-demonstration method was used, in the other the problem-solving method. Barnard found that, although the lecture-demonstration method was superior with respect to specific information, the problem-solving approach was superior with respect to the development of problem-solving ability and the formation of attitudes. A little thought will make this less surprising. The lecture-demonstration technique emphasized specific information, and the students learned the facts better (as determined by immediate recall testing) than did the students who were engaged in problem solving. The latter group were solving problems in which facts were used in relation to the problems being attacked. They not only learned to solve problems by solving them, they also gave evidence of a greater development of "sound" attitudes, because their viewpoints were being challenged by the nature of the problems attacked.

Unfortunately, there are few studies that undertake to determine, under adequate controls, the level of abilities, facts, and understandings that are retained over long periods of time following work in science courses. Those that have been made, and there are several, indicate, as did the study of Freud and Cheronis, that principles, theories, and applications remembered better than unrelated facts. The experimental group in the Barnard study might, therefore, show a superiority even in factual recall if tested a year or so after the instruction.

One final study will be reported which almost epitomizes the results of dozens of other studies that have been made before and after. Blair and Goodson[33] attempted to teach directly several of the scientific attitudes and various elements of the scientific method. They used three groups of ninth-grade students. One group was taught by conventional methods. Another group was not studying science at all. A third experimental group was taught the regular course together with specific training in scientific thinking. The results were determined by the use of Noll's test, *What Do You Think?*, Form I. The investigators found that

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[31] William A. Kilgore, *Identification of Ability to Apply Principles of Physics* (Contributions to Education No. 840; New York: Bureau of Publications, Teachers College, Columbia University, 1941).

[32] John D. Barnard, "The Lecture-Demonstration versus the Problem-Solving Method of Teaching a College Science Course" (Doctoral dissertation, New York University, 1941).

[33] Blair and Goodson, *loc. cit.*

there was a marked improvement in scientific thinking "when special attention is given to obtaining this outcome and when specialized learning exercises . . . are utilized."

Psychological theory, empirical data from general psychological research, and investigations in science education, as well as common sense, emphasize and document the judgment that one learns only by doing. This means that the effective science teacher will clarify what he wants his students to learn and then will give them experience directed precisely to that learning. If he wants his students merely to learn to state principles, recall facts, or work paper and pencil exercises involving quantitative relations, he will provide them with precisely these experiences. If he wants his students to become more critical-minded, he will provide them with experiences requiring the application of critical thought processes. If he wants them to develop skill in applying the principles of science to out-of-school life, he will provide experiences precisely designed to teach his students such applications. If he wants his students to develop the ability to locate problems that are real and important to them and to apply the methods of science and the tested data that science provides to these problems, he will provide them with experiences designed to develop prowess precisely in these skills. Once the science teacher faces squarely the indubitable fact that one learns only from what one experiences, he will see the futility of assuming that a teaching procedure that emphasizes factual recall to the exclusion of other experiences will develop abilities other than factual recall. And even factual recall recedes in a short time, if we may believe the evidence from research on the subject.

Direct and Vicarious Experiences in the Science Class

Not all experiencing need be direct to be educative. The lower animals may learn only through direct experiencing. But it is quite clear that the human being can, and does, learn through vicarious experiences. Man utilizes charts, graphs, words, pictures, and other symbols in his learning processes. While he is reading a book or attending a play, he need not suffer direct pain to appreciate the pain that a character in the book or play is suffering. He need not have tuberculosis to understand and appreciate the gravity of the disease, the nature of the symptoms, and its etiology. But someone who has never suffered pain cannot empathize with a fictional character who suffers pain. Nor can anyone be expected to gain a usable understanding of a specific disease unless he had some familiarity with the general nature of disease from direct experience. Much sterile health instruction has resulted from general ignorance of this fact.

It is important that the science teacher recognize the primacy of direct experience over vicarious experience and that he understand the relative meaninglessness of science teaching that is not rooted in the experiences the students bring to the classroom. He should be constantly alert to so focus the facts and principles he is teaching that his students can see their relation to actual experiences that

they have had and are having. A major mistake of science teachers is developing the science course as a gem of organized logic without reference to the necessity of "psychological logic." Psychological logic is required if learnings are to be real and durable. Learnings which are not seen by the student as relevant to his personal life and experiences are, like meaningless word patterns, poorly learned, if at all, and poorly retained. Read the words that appear at the bottom of this paragraph. These are good English words. You already know them all and their meanings. In this you are ahead of the science student who meets many new technical words that are totally novel. The words below are well-known words to you. After reading the "sentence" once, look up from the page and attempt to repeat it. "Sense make doesn't it because remembered and learned be readily cannot this."

Read it again and attempt to repeat it. By repeated readings and attempts you will finally be able to do the job. But can you remember it? Could you repeat it tomorrow? a week from now? a year from now? Probably not. The mind cannot grasp, nor can the memory hold, meaningless patterns. The mind searches for clues to meaning. When meaning cannot be found, learning, in other than a memoriter recall sense, is impossible.

Read the sentence again but start with the last word and move to the beginning. It then reads, "This cannot readily be learned and remembered because it doesn't make sense." Now look up and see if you can repeat it. The chances are that you can do so without difficulty. And if you knew that you were going to be asked to repeat the sentence tomorrow, a week from now, or a year from now—in other words, if you were given even some extrinsic reason for remembering it—you probably would have no great difficulty in doing so. You might not be able to state it verbatim. You might say: "This sentence is hard to understand and to keep in mind because it is senseless." But note the point. Once you have caught the meaning of the sentence it no longer matters whether or not you can repeat it verbatim. *The important thing is that you have caught the meaning.* Now, without violence to the thought, you can adjust the precise form and ordering of the words. You can even omit words and add others, but the meaning will still be there. Furthermore, the fact that you have caught the meaning of the sentence makes it far easier for you to remember even the separate words and their order. For you now have a framework of meaning in which to relate the parts. Until you understood this larger meaning, the subparts—the specific words—had no real meaning and no apparent relation to each other. Therefore, they were difficult to remember. Once the meaning of the whole was clear, you could far more readily remember even the precise words of the rephrased statement.

Science, as it is taught to young people, is too often like a series of unrelated words. The teacher is trained in the field and is a mature person. He has forgotten all the blind alleys his mind took when he first studied science. He now sees his subject as a related whole. He sometimes fails to see how meaningless and purely verbalistic some of his teaching is. His subject makes sense to him

precisely because he is a mature person in the field. He can see and understand the specific facts because he sees them in their meaningful relations to the larger field of science. But, to the student, the facts may be as meaningless as the words in the nonsense sentence above. And he may fail as dismally in seeing the larger concepts and generalizations of the science as did the reader when he attempted to repeat the entire nonsense sentence.

There is always danger that the student may not be able to see the woods for the trees. There is danger that he may not be able to distinguish one tree from another. The teacher's first job is to help his students understand the meaning of material to be learned. He can do this only if he can break down the internal organization, which is useful to the mature scholar, and reshape it in such fashion that the student sees it as meaningful in terms of his own background, interests, purposes, and concerns. When this is done, meaningful learning experiences can proceed, but not before.

A SUMMARY OF PRINCIPLES OF LEARNING APPLIED TO SCIENCE TEACHING

1. *All learning is purposive. The degree to which the student finds an intrinsic purpose in educational activities, such as demonstrations, discussions, experiments, and other forms of science study, is the degree to which real, as against verbalistic, learnings are possible.*

The science teacher should consider carefully whether the educational experiences he provides for his students are seen by them, as individuals, to be purposive—to be important learnings. The teacher should not be fooled by the fact that his students can, and do, develop the ability to respond successfully to paper and pencil tests into believing that this necessarily represents real learnings; for if the student's only purpose in learning certain science facts or principles is to develop the verbalistic skill necessary to succeed in an examination or the course he may develop precisely these abilities and little more. If the student is brought to understand the importance and value to him of proposed science learnings, then he will have an insight into them and a goal for learning that will produce understandings, attitudes, and skills that meet his purposes and help him to achieve his goals. This does not imply that the teacher must follow the whims and casual interests of his students and ignore areas of learning that he knows to be of real worth to his students. It does suggest that the teacher will be unsuccessful in teaching the most highly desirable learnings if the learner does not accept them as important and valuable. The teacher's first job, then, is to challenge the thinking of his students to the point that they share, with him, an insight into the intrinsic worth of the learnings. Extrinsic motivations such as threats and awards without a doubt produce a species of learning. But the student may then work merely to achieve the extrinsic awards or to avoid the

penalties implied in the threats, and once these goals are attained, his "learnings" recede to the vanishing point.

For these reasons, among others, modern science teachers spend a considerable amount of time planning units of work with their students. The planning period gives the teacher an opportunity to learn the students' backgrounds, interests, and present insights. It gives the teacher a chance to adjust the organization and development of the proposed unit so as to capitalize on his students' interests and help them see the meaning of the area to their lives and concerns. Unless the teacher succeeds in this process of intrinsic motivation, he might as well move on to another area, for it is an extravagant waste of time for teachers to try "to get across" material for which students see no value. (Chapters 6, 7, 8, 9, and 10 provide detailed suggestions for intrinsic motivation under various instructional plans and for various types of instructional material.)

As long as schools are organized in such a fashion and science teachers teach in such a manner that considerable material of no known or clearly seen value to the students is taught, extrinsic motivation in the forms of rewards and punishments must be provided. If all the boys and girls in a general-science class are required to study about the Bessemer converter from a single text, with the same emphases, and at the same pace, some form of whip must remain in the hands of the teacher. The average teacher would probably be hard pressed to state in any defensible terms why his students should study about the Bessemer converter. Yet, a treatment of the subject appears in most general-science texts and in practically all chemistry texts. Some children may find the topic absorbing. But it is certain that the average student studies about the Bessemer converter for one reason only. He is faced by the authority of the teacher and the school and must learn it for the purpose of receiving a good grade and avoiding censure.

Teachers sometimes remark that their children are so hostile to learning that they must stand in front of the room with grade book in hand and mark each student as he recites; otherwise, the students would not study or work. True enough. If the teacher is unwilling to revise his offering in such a fashion that his students will agree that the material is important, the teacher must crack the whip. But education under such conditions is a farce and provides one of the reasons why so many people come to fear and dislike science. A science course should be a milestone in science learning—not a gravestone!

2. *Learning is a complex, and the learner learns many things at one time and learns as a complete organism.*

For purposes of analysis it is sometimes useful to break down educational objectives into knowledge, understandings, attitudes, and skills. But the student can never learn a fact, a concept, or a principle without certain concomitant learnings and changes in his total personality. The science teacher should maintain a critical awareness of this fact. While his students are learning to balance equations in chemistry they are learning many other things at the same time. Just what they learn will depend upon their total motivation in the situation.

They may learn to cheat, to hate chemistry, to find the pride of good workmanship, or to command the respect of their peers. The master science teacher will create a wholesome learning situation so that the entire range of his objectives of developing a human personality may be reached, through even the simple process of instruction in the balancing of equations. If he is interested in developing democratic personalities and increased skills in cooperative group processes, he will provide the setting for this development. He will not be an autocrat in the classroom and expect that his demands as a dictator will not evoke aggressiveness or irresponsibility, or distaste for science.

The science teacher, like every other teacher in the school, directly and heavily affects the development or retrogression of personality traits by his day-by-day teaching practice. The child simply cannot be broken down and only his "fact-gathering-and-using" faculty employed in a learning situation. The child is an individual personality of infinite worth. And he learns as a total personality and organism. It is up to the teacher of science to recognize this fundamental truth and to teach accordingly.

3. *Learnings will be transferred to the extent that the learner sees the possibility of transfer to other situations where the learning is applicable; to the extent that he has generalized from his learnings so that he understands the principles involved; and to the extent that he is given practice in transferring these generalized insights into new situations.*

Science, as a field, is not concerned with the particular. Science is concerned with those generic truths which can be stated as principles, or laws of sufficient general scope that they can be applied, with better bases of control and prediction, to new situations. There would be little profit in learning about gravitation if every object had its own unique attractive force directed to as many different objects, each with its own unique attractive force. The value of science is that it is possible to elicit from specific cases generalized principles that will apply with equal validity and accuracy to a wide universe of other specifics.

The science teacher, therefore, has no legitimate interest in having his students learn a conglomeration of discrete facts that, being discrete, will not function in the great range of activities and affairs of their lives. He must recognize that his students are being taught at the expense of patrons or taxpayers so that they may mature into effective persons and citizens, capable of controlling their affairs and the affairs of a democratic society with efficiency and wisdom. This means that the only learnings that are of real worth are those that have high transfer value to the student's daily life and to his affairs as a democratic citizen or that have clear preparatory worth for those that will go on to college or to jobs.

Thus, the science teacher is charged with the responsibility of helping his students to bring order to the natural world of living and nonliving things and and transfer the learnings of the classroom into their daily personal and social of helping them develop generalized insights so that they may build upon them lives.

The evidence is distinct and emphatic that the ability of a student to transfer a learning to other situations depends on his being helped to see the possibilities of transfer. This does not mean that the teacher must reveal to his students the entire range of possible applications. This would be patently impossible, and, furthermore, it is not necessary. What is necessary, if the learning is to function in the student's life, is that the teacher help the student to see some applications of the learning to things that he is familiar with and that the teacher provide additional, novel situations to give the student opportunity to make the transfer "under his own steam." If the student cannot do this, real learning has not occurred, and further teaching is required.

It is not sufficient for the teacher to provide the student with an insight into the transferability of a technical learning from one technical context to another technical context completely divorced from the student's life. If science is to operate in the life of the student, he must be helped to understand those principles that are valid and relevant to *his* affairs and to see *how* they are relevant and will affect his life for the better. If he can be brought to see such possibilities in what he is learning, and if he is given an opportunity to practice such applications, the teacher can feel confident that he is making science a living part of the student's life. This is the nature of the teacher's responsibility. If he cannot do this and demonstrate that it is being done, all the high scores on the standardized evaluation instruments in the world will not change the fact that he has failed as a science teacher.

Teach for meaningful understandings and the use of those principles that are relevant to a student's life. Help the student until he sees the applicability of such principles to a range of activities and affairs of importance to him and to society. Help the student make successful applications to some of these activities and affairs. And test whether the learning has become functional by providing novel situations wherein the student's power to use his learnings may be demonstrated. This is effective science teaching.

4. *Generalizations are, by definition, that which one generalizes out of concrete experiences. Principles (generalizations) probably cannot be understood, other than as empty verbalisms, except through the inductive process of studying concrete situations out of which generalized insights may emerge.*

Generalizations are too often taught as verbalisms. They are taught as if they were facts. There is a great distinction between the development of a generalized insight and the development of the ability to write or state the words which express the insight that scientists have developed concerning certain relations. Many, many students have learned to say, "A body immersed in a fluid is buoyed up by a force equal to the weight of the fluid displaced," and have not the foggiest notion of the relations that are expressed by this statement. It is of no vast importance that a student learn to state a principle in precise fashion. The important thing is that a student understand the principle that is operating—that is, that he understand the relations that the principle expresses. Once he has

developed an understanding of the relations, he can make his own statement with sufficient precision to suffice for all ordinary purposes. And he will retain even the ability to state the principle much longer than will the student who has learned only the verbalism, because the student who understands the principle knows what the statement means; it is not a nonsense phrase to him.

A generalization is not something written on paper. It is something that happens inside a learner. Since a generalization is something that happens internally and is not a memoriter learning to be stated trippingly on the tongue, it cannot be learned except through the process of studying the real problem situations or phenomena in which the principle operates. Then, conclusions may be formed that square with the facts observed, and after evidence is found that certain relations always obtain, the student may come to understand the generalized truths that he has observed.

The laws and principles of science were developed precisely through such an inductive process. Men found problems or interesting phenomena. They tackled these problems, studied the phenomena, and came to certain tentative conclusions regarding the causative factors operating. As they focused on an increasing range of problems and found that the relations were always the same, within the limitations defined, they began to take a more generalized viewpoint toward them and were able to state these relations as general propositions or laws. This is the way that the student should be brought to learn the principles of science. Once learned in such a manner, application to other situations is possible.

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THE IMPROVEMENT OF CLASSROOM PRACTICE

III

6

NEWER PATTERNS OF COURSE OFFERINGS

In the days of the academies, a wide variety of science courses were offered in specific areas of science (see Chapter 3, page 61). But, with the standardization of the high schools during the latter part of the nineteenth century and the early decades of the twentieth, came a severe narrowing and standardization of science courses. For several decades, now, general science, biology, physics, and chemistry have constituted the typical science offerings in the schools of the United States. Few high schools or senior high schools in the country today offer less than general science, biology, physics, and chemistry, although many small high schools alternate a year of physics with a year of chemistry, as a necessary economy when the staff and the student enrollment are small.

In the last decade or two, high schools have increasingly offered additional science courses. In a study of the U.S. Office of Education published in 1950,[1] a report was made of these offerings from a sample of 715 high schools over the United States. Of the 715 reporting schools, 135, or about 19 per cent, reported additional or alternate science courses. Sixty-one schools included physical-science courses of one kind or another. Chemistry and physics were often taught with materials from meteorology, astronomy, and geology. Forty-nine schools offered broad science courses, apparently without regard to subject-matter lines between the biological and physical sciences. Twenty-five schools offered additional

[1] Philip G. Johnson, *The Teaching of Science in Public High Schools* (U.S. Office of Education, *Bulletin* No. 9; Washington: Government Printing Office, 1950).

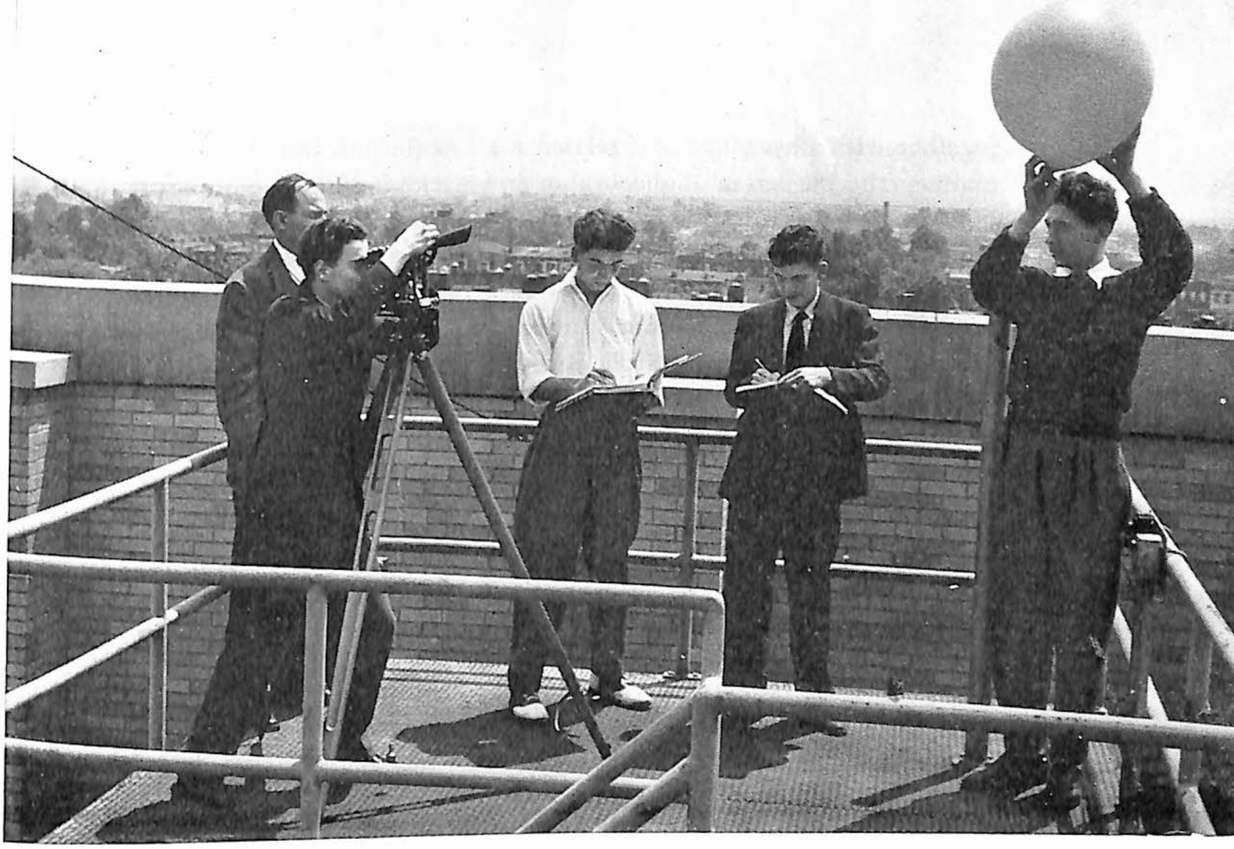
biological science courses. The most common additional or alternate offering could best be described as an "applied-science" course. In addition, offerings included specific courses in physiology, earth science, electricity and radio, science of aviation, and photography.

LIMITED VALUES OF APPLIED SCIENCE COURSES

One looks at this proliferation of course offerings with some misgivings. There are undeniable advantages to a structured organization of a discipline. This is not to say that the student must learn the discipline in the step-one, step-two fashion that has been so commonly attempted in science classrooms throughout the nation. But, if learnings are not to be chaotic, the time must come when the learner understands the internal logic of the discipline itself. He must understand the interrelations that obtain between related theories and dependent bodies of fact.

A typical—and probably justified—criticism of "applied science" and similar courses is that they too often go around the science itself. There is much talk and reading *about* science but little study of the science itself. There is discussion of the applications of science but little or no analysis of the fundamental principles and body of data from which the applications derive. This is not science teaching. It may have its usefulness, but it cannot produce the disciplined minds that can theoretically emerge from the disciplined study of science—and other disciplines. It is necessary to reiterate that we are not speaking of the textbook-dominated race over facts that too often masks as disciplined study when we speak of the power of the disciplines to develop disciplined minds. Nor are we suggesting a faculty psychology. We simply mean that each major discipline or subject area has developed its own methodology and that there is profit in studying these methodologies. That of science (loosely called the scientific method and attitude) can make a significant difference in the student's intellectual life. But observation of many of the newer "applied-science" courses leaves one with the impression that many science teachers, in leaving the too-ordered path of the textbook, have lost their way entirely. Or—more commonly—they are employing "applied science" textbooks that are as worthless in their power to develop intellectual maturity as a semester's perusal of the Sunday supplement of some of the more shoddy metropolitan newspapers.

A legitimate word of caution can also be expressed concerning such courses as "photography." If a school is large enough and wealthy enough to offer sound and intensive work in the basic sciences and, in addition, to offer hobby- and skill-development courses in various applied branches of science, all the better. But to offer such courses in lieu of fundamental learning experiences in science disciplines is to misunderstand the basic responsibilities of science education in our time. Applied courses may develop trained technicians and hobbiests—and



The value of applied science courses for vocational orientation and training is, of course, great. But technician training, valuable as it is, should not be permitted to replace general education courses in the sciences. (Official photograph, Board of Education, City of New York)

there is no objection to this. But technical training and skill development in vocational pursuits must be undergirded by fundamental learnings designed to develop intellectual, emotional, and ethical maturity. If a school is too small to afford fundamental science courses and such peripheral courses, it is wise to stay with the basic sciences and make them the fascinating and disciplining subjects they can be.

THE LOGIC BEHIND THE NEWER COURSE OFFERINGS

In the foregoing section we have raised certain objections and cautions concerning *some kinds* of newer course offerings. We do not wish to be misunderstood in this. We are *not* objecting to all forms of experimental departures from the traditional offerings of biology, physics, and chemistry. There was a time when zoology and botany were offered in our high schools instead of biology. Few would now suggest that we go back to the teaching of the separate disciplines. Biology—which represents at its best an integral fusing of zoology and botany,

together with physiology and related biological fields—can be taught in such a manner that it has a higher value in developing mature understandings of biological phenomena related to the life of man than zoology and botany, taught separately, ever could.

There is no logical reason, therefore, to damn attempts to provide a similar fusing of physics and chemistry into an organic and dynamic science in which related disciplines and applied branches are brought into their proper relations. Life does not present its problems in separate and neatly identified bundles of physics, chemistry, astronomy, and geology—or of light, heat, sound, magnetism, electricity, and mechanics, for that matter. If the science is to live in the life of the learner, there are good psychological reasons to believe that it can best be taught through the relations that exist in the real world outside the classroom walls.

The traditional organization of the separate disciplines of science illustrates a fatal separateness in teaching important ideas, principles, and values that, in life, must be interwoven. It is with this awareness in mind, and because the results of conventional instruction have not generally produced the liberally educated young men and women we have wished for, that both colleges and high schools have experimented with newer methods of organizing science courses.

Attempts at integration, unification, and interdisciplinary analysis have been attempted in large part in response to observed inadequacies of the standard curriculum. But there is, in addition, a substantial body of psychological and sociological theory that lends support to the enterprise. Hilgard has stated,[2]

> The typical pattern of motivated behavior is that of a need leading to a drive. The drive state is one of restlessness and heightened tension, leading at first to random activity and later, through learning, to genuine seeking (or avoiding) behavior.

Efficient learning occurs when the learner is led to see how *his* needs may be satisfied. If his state of tension or need derives from a necessity to win social approval or a grade, his learnings will be quite different than if the school has recognized existent "real-life needs" and has organized the instructional program in such a fashion that these form the basis of significant learning activities. A good deal, of course, depends upon what is done with the problems and needs that are real to the student. If they merely foster superficial discussion, they clearly are of slight educational value. (It is to such "applied-science" courses that we objected earlier.) But if they form the basis for increasingly efficient and responsible analysis and sound generalizations, we can expect that more durable and functional science learnings will occur than would be possible under the strait-jacketed approach of the conventional science classroom.

What science teachers have often done is to assist young people to see how the

[2] Ernest R. Hilgard, *Introduction to Psychology* (New York: Harcourt, Brace and Company, Inc., 1953), p. 117.

disciplines themselves can help them understand and resolve both personal and social problems. The disciplines have been used not only to meet the immediate needs or drive states of the learner but also to give him a beginning appreciation of and skill in the methodologies of the disciplines themselves. *Real* attacks on personal and social problems cannot be made without serious, sustained intellectual effort and considerable investigation and analysis. The best of the newer science programs are therefore structured around real and significant personal problems that by nature are interdisciplinary, and they use these problems to develop intensive and disciplined study of the sciences.

Many years ago, James Harvey Robinson wrote,[3]

> Both the textbooks and manuals used in formal teaching . . . tend, almost without exception, to classify knowledge under generally accepted headings. They have a specious logic and orderliness which appeals to the academic mind. They, therefore, suit the teachers fairly well, but unhappily do not inspire the learners.

Alfred North Whitehead, the great philosopher and mathematician has written,[4]

> Let the main ideas which are introduced into a child's education be few and important, and let them be thrown into every combination possible. The child should understand their application here and now in the circumstances of his actual life.
>
> The mind is never passive; it is a perpetual activity, delicate, receptive, responsive to stimulus. You cannot postpone its life until you have sharpened it. Whatever interest attaches to your subject-matter must be evoked here and now; whatever powers you are strengthening in the pupil, must be exercised here and now; whatever possibilities of mental life your teaching should impart, must be exhibited here and now.
>
> The solution which I am urging [to vitalize learning and to get away from "inert" ideas] is to eradicate the fatal disconnection of subjects which kills the vitality of our modern curriculum. There is only one subject-matter for education, and that is Life in all its manifestations. Instead of this single unity, we offer children . . . Algebra, from which nothing follows; Geometry, from which nothing follows; a Couple of Languages, never mastered; and lastly, most dreary of all, Literature, represented by plays of Shakespeare, with philological notes and short analyses of plot and character to be in substance committed to memory. Can such

[3] James Harvey Robinson, *The Humanizing of Knowledge* (New York: Doubleday & Company, Inc., 1924), p. 67.

[4] Alfred North Whitehead, *The Aims of Education and Other Essays* (A Mentor book; New York: New American Library, 1949), pp. 14, 18, 19.

a list be said to represent Life, as it is known in the midst of the living of it? The best that can be said of it is, that it is a rapid table of contents which a deity might run over in his mind while he was thinking of creating a world, and had not yet determined how to put it together.

A cogent statement on the lack of psychological logic found in the traditionally organized disciplines is that of Smith, Stanley, and Shores,[5]

> How far removed the logical subject organization is from the personal organization of functional knowledge can easily be seen in a person's own experience. Anyone who will take the trouble to examine his own organization and retention of knowledge [except, of course, the specialist in academic work in his own discipline] will find that his useful and effective knowledge has collected about certain poles, or nuclei of interests, which have somehow come to play a significant role in his thought and action. The tearing apart of these centers of interest and knowledge, and the arrangement of their content into a logical system—such as is found in the subject curriculum—constitute a laborious and painful undertaking. The converse, the breaking up of the subject organization and the mobilization of this content for effective attack on problems, is no less difficult. The plain fact is that the organization of ideas—or for that matter of anything else—depends upon the purpose. Since the purposes of the learner are seldom the purposes implied by the subject curriculum, the organization is of necessity often alien to the centers of interest about which the experience of the learner crystalizes.

These, then, are the reasons for the experimental attempts to reorder the science courses. First, the available evidence concerning the conventional logical organization of science into tight compartments indicates that our aims are not being achieved as fully as we would like. Second, the very nature of our present responsibilities in a world so heavily influenced by science and technology requires that we teach young people about the real world, in which the various phases of science are interwoven with other disciplines into a living fabric of problems, needs, and issues. Third, the psychology of the learning process clearly indicates that efficient, functional, and durable learnings are the product of instruction that is centered in the personal and social problems of the learner. These problems, being real, are never divisible into tight packages that can be labeled "chemistry," "physics," or "botany." Such courses are important, but they should be deferred until the student has a substantial grasp of the broad aspects of science that are intimately related to his own life and that of society.

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[5] B. Othanel Smith, William O. Stanley, and J. Harlan Shores, *Fundamentals of Curriculum Development* (Yonkers, N.Y.: World Book Company, 1950), pp. 396, 397.

AN EXAMPLE OF A FUNCTIONAL ORDERING OF SCIENCE CONTENT

As indicated in Chapter 2, it is extremely difficult to describe in detail the nature of one of the newer group-planned, problem-centered, and dynamic courses in science. But it may help the reader who has not observed the newer programs in action to study one example of the basic pattern such courses might take. The one chosen is adapted slightly from a proposal written some years ago and at least partly tried out by Paul Brandwein at Forest Hills High School, New York. It is presented with his permission.[6] It presents a tentative outline for a course of study in science which is designed to provide continuous experiences in science for four years in high school. Brandwein stressed the tentativeness of his proposal and declared that "it would require a particular type of rashness to assume that there is any one way of presenting such science." But the plan illustrates clearly the conception of teaching science around foci of interests and needs that cut across subject matter lines. It merits careful study.

Brandwein's proposal was partly the outgrowth of trial runs in which science experiences were organized under the problems of living. On this point he states,

> In these trials, when respiration was studied, for instance, the structure and function of the respiratory organs were examined; alveolar structures were studied under the microscope; dissections were made; oxygen and nitrogen were prepared and their properties (in relation to respiration) were studied; and the principles affecting the behavior of gases were considered. In this very brief account of a minute division of science, it is clear that subject matter usually considered under general science, biology, chemistry, and physics was combined into one experience concerned with a life problem.
>
> The four years of science [in the proposed course of study] are arbitrarily titled *Science and the Individual, Science and the Family, Science and the Community*, and *Science and the World*. These titles are not merely names. Emphasis is not placed on subject matter, but subject matter is to be learned only as it serves the personal, socio-personal, socio-civic, and socio-economic needs of the individual. The need of the individual to be a healthy functioning citizen involves biology and chemistry, as well as physics and also other fields. The need of the individual to be adequately housed is related to the biology, chemistry, and physics of sewage disposal; the biology of the effect of sunlight on growth and disease; the chemistry of construction materials; the physics of forces; moments; refrigeration and ventilation—to mention but a few aspects. In a science curriculum based upon a traditional

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[6] Paul F. Brandwein, "Four Years of Science," *Science Education* 29:31–32 (February), 1945.

course in chemistry, biology, and physics, the teachers of any one of these regularly delay complete solution of any problem till another cubicle of science is entered. In fact, many of them console themselves by answering students' questions with the statement, "We can't take this up here, wait till you get to physics." Possibly the boy or girl never reaches physics.

If it is a requirement of our age that boys and girls must understand their environment, then teachers of science should fulfill their function of furnishing the continuous experiences necessary for the understanding of these problems. And in much the same way that a need is an interaction between the desires of the individual and the desires of the society in which he lives, so problems of living generally involve the interaction of an organism (a biological entity) with its physical and chemical environment. This is merely to emphasize that problems of our world are solved by individuals who can correlate or fuse different areas of experience. This activity, our reasoning leads us to believe, may be served best by similar experiences in the learning situation devised in school.

It is clear that the sequence to follow may be modified in the particular learning situation. As a matter of fact, one of the advantages of the organization is that subject matter is used only as it answers a desirable or necessary problem. It should be just as clear that a complete syllabus cannot be presented—the topics in parenthesis are merely suggestive and should serve as a frame of reference.

SCIENCE IN LIFE AND LIVING

I. Science and the Individual

  A. Problems in adequate nutrition
  Kinds of food; nutrients; chemistry and physics of digestion and absorption; chemistry of oxidation; diets in relation to health; the consumer

  B. The function and structure of the body
  Biology, chemistry, and physics of respiration; biology and chemistry of blood; physics and biology of blood pressure; vision and hearing; introductory physics of light and sound; chemical tests of urine and sweat; excretion; first aid

  C. Prevention of disease
  Water-borne diseases; airborne diseases; human carriers; infection and contagion; applied chemistry of antiseptics and chlorination; immunity; public health measures; sewage disposal

D. A person's behavior
Structure and function of the nervous system in relation to learning and to habit formation

E. Leisure activities
Photography; nature study; pets; tropical fish; growing plants; radio; engineering activities; airplane models and aviation

II. Science and the Family

A. Reproduction
Reproduction of common animals; individual or group conferences on human reproduction where classes are mixed, or class discussion in segregated classes; prenatal care

B. Heredity
Principles of heredity; environment and heredity; application to human beings; marriage; the early environment of the infant

C. Safety in the home
Prevention of accidents; the medicine cabinet; review of first aid

D. The home chemist
Chemistry of cooking and cleaning; chemistry and physics of clothing

E. The home electrician
Understanding electrical appliances at home; practical experience

F. The home biologist
Maintenance of food to avoid spoiling; elements of nursing the sick person; growing plants; care of pets; care of young children

III. Science in the Community

A. Eugenic factors
Improvement of the individual as a community problem; feeblemindedness; birth rate and death rate; war as a destroyer of germ plasm and productive citizens

1. Personal services
Recreation; medical services; education

2. Improvement of food
Chemistry and biology of photosynthesis; heredity and biologic production

3. Improvement of soils
Chemistry of soils; hydroponics; practical gardening; fertilizers; physics of erosion; biological organisms; agricultural practices

4. Conservation of resources
   Coal, metals, minerals and mining practices; forest and lumbering practices
5. Housing
   Chemistry of materials; physics of structure; heating, ventilating, humidifying, refrigeration; biologic factors
6. Energy
   Chemical energy for muscles, including a fuller analysis of chemical changes in blood and muscles than usual; machines; fuels; water power, electricity; future of atomic power
7. Communication
   Telephone, radio, radar, television; automobile, locomotive airplane, fuller treatment of light, sound, and wave physics; electronics; chemistry and physics of the combustion engine; aviation physics

IV. Science and the World

A. Science and technology
   Effect on world economy; employment, leisure, communication; interrelationship among people
B. Racial understanding
   Evolution of man and human races; racial understanding; brief psychology of human relations
C. The life span
   Birth rate and death rate; factors affecting productive life and health.

The foregoing outline might be the basis of a series of textbooks, a rote excursion over the top and around the edges of science, or it might be—as Brandwein intended it—a guide to intensive, critical, and exploratory learnings in which basic facts and fundamental principles of science are developed in an increasingly disciplined fashion. The point of interest in the outline is that it provides a different, and possibly better, basis for the organization of learning activities for the purposes of general education than that usually provided in the conventional courses in the separate sciences. Similar programs have been tried out in a number of schools in the United States.

OTHER PATTERNS OF SCIENCE OFFERINGS

The problem of accommodating instruction to the various abilities and interest levels of the wide variety of youth who attend our high schools is particularly vexing to many teachers. The kind of program that Brandwein envisaged and the type of instruction that has been recommended in other chapters of this volume are designed to take care of these differences in the students, for they

provide a rich resource of learning materials and experiences, and each student can "find his own level" in terms of his native endowments.

The Double-Track System

In many high schools today, students enroll in science courses of two different sorts according to their ability as determined by such factors as average high school grades, tested intelligence, aptitude, and so forth. The poorer students are placed in "applied-science" courses or in courses that provide less intensive treatment of basic sciences. The better students are placed in more conventional courses in the sciences. This "double-track" system of placing children in more homogeneous groups according to ability is both supported and condemned by educational theorists today.

Substantial arguments can be presented on each side of the question. In many of the double-track systems, the poorer students soon come to know that they are in a "dumping ground" course, and there is considerable lethargy in both the teaching and the learning that goes on as science is talked about with a minimum of demonstrations, no experiments, and largely verbalistic experiences. Such programs are particularly to be condemned. But the double-track program can offer instruction better adjusted to the abilities of students than is commonly offered in conventional single-track programs. High-ability students are not likely to be neglected if low-ability students are taught in separate courses. Low-ability students can be given the multisensory learning experiences they need if the teacher need not deal with more abstract or technical matters for the benefit of high-ability students who learn easily and understand readily.

A balanced and comprehensive consideration of the double-track system would require a chapter in itself and is beyond the scope of this book. Suffice it to say that it is used by many schools for science and other academic subjects and that it has its strengths and weaknesses, proponents and opponents. Simplifying some phases of the educational process, it creates difficulties of its own.[7]

The Common-Learnings Course and Science

Over the last two decades there has been a definite trend toward offering a new type of course that cuts across all subject-matter lines in science and other subjects. Such courses are problem-centered and group-planned. They are generally required of all students and go under the names of "common-learnings," "core," or "basic-education" courses.[8] Chapter 9 describes how one science

[7] Research bearing on the subject of ability grouping is summarized in Walter S. Monroe, *Encyclopedia of Educational Research* (rev. ed.; New York: The Macmillan Company, 1952). See particularly pp. 376–378 and 1168.

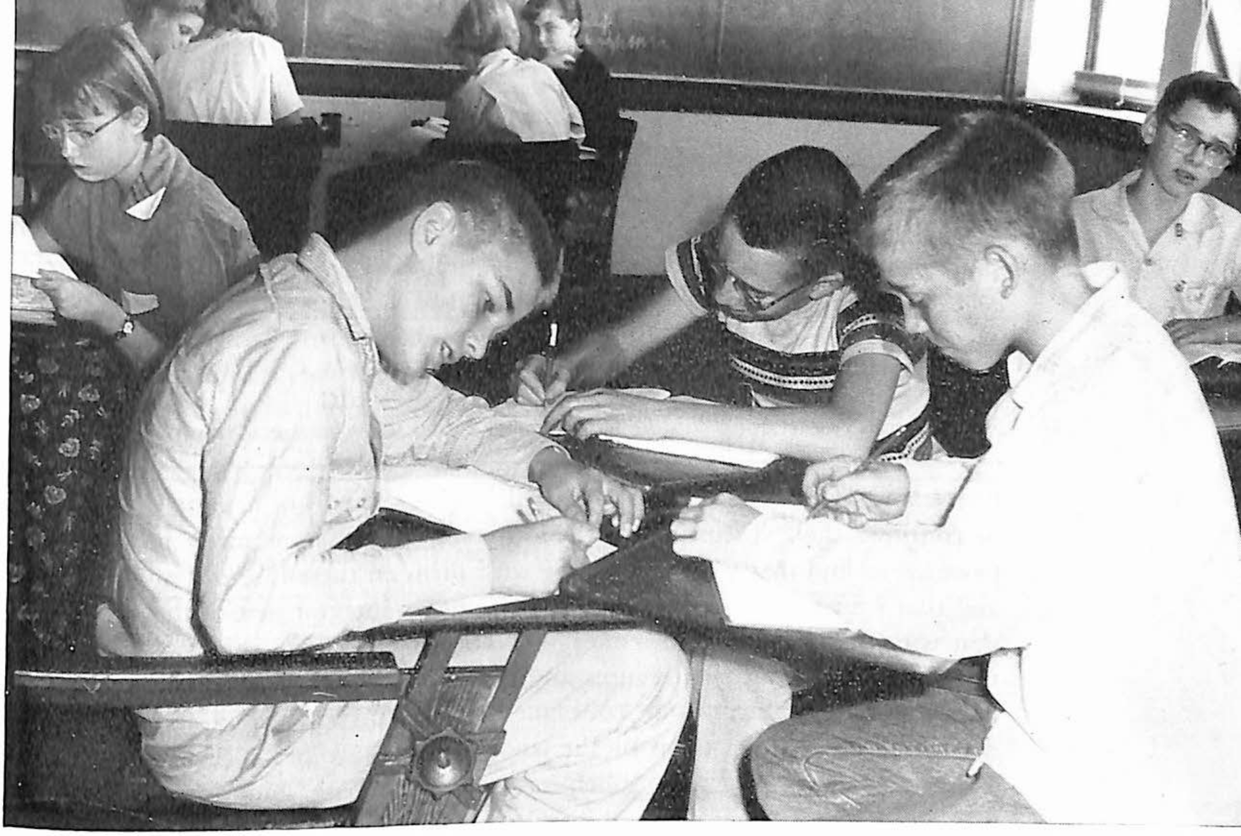
[8] For further information, see Educational Policies Commission, *Education for All American Youth* (Washington: National Education Association, 1944); R. Will Burnett (ed.), *Core Programs in Action* (this is the title of the January, 1953, issue of *Education*, Vol. 73, No. 5; it presents a number of vignettes of core programs written by the teachers who conduct them); Harold C. Hand, "The Case for the Common Learnings Course," *Science Education*, 32:5–11 (February), 1948.

teacher taught a major unit in atomic energy in a problem-centered core course.

The concept of the core program has considerable theoretical sanction, and there is a fair amount of evidence that the results compare favorably with those obtained by more conventional methods of course organization. But the difficulty in the core programs, as far as science is concerned is, frankly, that the science usually just isn't there. Core courses are most commonly taught by social-science and English teachers. They cannot be expected to understand and teach the science that is omnipresent in most of the units of instruction that the students engage in. But there are many schools in which science forms a definite, prominent, and integral part of the instruction in core programs. These are schools where science teachers have undertaken the job of teaching and schools where the work is handled cooperatively by several—usually three—teachers. The pattern according to which this work is begun and the method by which each of the three teachers learns from the other two are of considerable interest.

Suppose that you are a science teacher in a particular high school and that you have been teaching for years by the methods and for the purposes that have been discussed in this book. By now you are aware of the fact that living problems have quantitative aspects, sociological aspects, communicative and esthetic aspects, as well as science involvements. You know that it is difficult to stop analysis and discussion simply because "that isn't science." You feel inadequate to step across the lines of your own specialized training, but you are concerned about the compartmentalization of your instruction. Furthermore, you recall the days when you hesitated to teach by a problem approach because there were a couple of areas of science in which you had little or no background and you were properly concerned that the students' pursuit of their interests might lead them into a morass from which you could not extricate them. Perhaps it is this recollection and your satisfaction in having learned that you, and your students as well, can engage in self-learning, if the motivation is strong enough and the materials for learning are at hand, that caused you to enter into the plans that were being laid for the development of a sound core program. You have studied the literature concerning core programs, and you know that they have produced excellent results—for some teachers. But you know also that core programs have failed miserably where teachers have rushed into them without preparation, careful planning, and the development of sound resource units and teaching materials. You volunteer to work with a committee of three teachers who plan to study and develop materials for two years before beginning the instruction. You are to represent science to the youngsters, and the other two teachers are specialists in English and social science, respectively. At the end of your planning and work period, you have learned a lot about the possibilities of incorporating English and social-science instruction into your new course. And your colleagues have learned a good deal about science instruction. But you do not dive into the deep, cold water of a new type of course. You test the water gradually.

Here is one pattern of cooperative teaching. The school administrators have



The relatively artificial boundary lines ordinarily separating the disciplines are withdrawn as students work on significant problems requiring interdisciplinary attack in core classes. (Courtesy of University High School, University of Illinois)

arranged your schedule and that of your colleagues so that you each teach three classes and then have a free hour in which you can plan or work together. These four periods follow one another, so you have the entire morning—or perhaps it is the afternoon—free for core teaching and conference work. The first period of the morning you have a group of about twenty-five students which we shall call Group A. During that hour the English teacher has another group, Group B. The social-science teacher has a third group, Group C. You teach your group the science aspects of a fundamental problem area while your colleagues are teaching their groups the social-science and communicative aspects.

For the second period of the day, your group—Group A—goes to the English teacher. Group B goes from the English teacher to the social-science teacher. And you get Group C, which was taught by the social-science teacher during the first period. When the third period comes around, the groups move again, so that, during the three periods of the day, each group has been taught by specialists in science, English, and social science concerning a basic problem area that has been agreed upon and planned for in advance. The table shown on page 150 illustrates how the groups move during the three periods.

It will not be long before the social-science and communicative problems begin to spill over into your classroom. The students cannot quite cut off their

ONE PATTERN OF COOPERATIVE CORE TEACHING

	Science Teacher	*English Teacher*	*Social Science Teacher*
Period I	Group A	Group B	Group C
Period II	Group C	Group A	Group B
Period III	Group B	Group C	Group A
Period IV	(Group conference and work by all three teachers—free period)		

interests and work when the school bell jangles the end of a period; they want to continue their discussion or their investigation. Before many months have passed, you find that you are working with them on these interests and problems and that your science has increasingly become an integral part of the instruction that is being offered by your colleagues. The same thing, of course, is happening to them. Your group conferences and cooperative work during the free period helps this along, too. Your colleagues raise many questions about science—questions forced upon them by the students who have been learning from you. You find that you are getting help on how to increase your students' speaking and writing skills and their ability to read critically. You are learning some important social science that just hadn't "stuck" when you took your formal courses in the subjects in college. You are learning from and with your students and your colleagues. If you continue this kind of teaching—and most competent core teachers find it the most rewarding teaching they have ever done—you find as the years go by that you have forgotten where the science stops and the other aspects take over. And it no longer matters. You are helping young people grow in intellectual capacity and in emotional and ethical maturity as you tackle significant living problems in which academic subject-matter lines simply do not exist.

There are other advantages to the block-of-time, cooperative core teaching which has been described. Whenever it seems desirable to get the three classes together for any purpose, it can be done. Perhaps you want to spend a morning —or a week of mornings—studying in the field or the community. Perhaps you are making a careful and original investigation of housing, sanitation, medical services, or the extent of racial prejudice. You have all the time you need. Or perhaps you want to use the services of an expert from the community—a physician, electronics engineer, economist, farmer, soil conservationist, or pathologist. The entire group can prepare to take fullest advantage of his visit and can utilize the whole morning for discussion with him. The core program we have described, breaks the lock step that the school bell so often places on fundamental and sustained learning activities.

The core program does not take the place of specialized courses in science or other fields. It is merely the part of the total program that is required of all students and is devoted to frontal consideration of fundamental personal and social problems. If sloppily handled, the core program can be a farce and a

travesty of sound education. If carefully planned and intelligently executed, it has certain advantages over the fifty-minute-period system of instruction in separate subject fields. Where core programs exist, you will still find biology, chemistry, and physics—and sometimes more. But the science that is fundamental to daily life and good citizenship is taught in the required core courses. The structured disciplines are taught as electives to all who can profit from them, and all qualified students are encouraged to elect them. The following chart represents the daily pattern of courses in a hypothetical six-year high school.

THE CURRICULUM OF A SIX-YEAR HIGH SCHOOL
UTILIZING THE CORE

Grade:	*7*	*8*	*9*	*10*	*11*	*12*
Period: 1	Core program: Required of all students; three periods a day for the seventh, eighth,					
2	and ninth grades; two periods a day for the tenth grade; and					
3	one period a day for the eleventh and twelfth				Electives in the sciences, arts,	
4					humanities, and applied and vocational fields	
5					include biology, physics, and chemistry	
6					(or physical science)	
7	Health and physical education one period a day for each of the six years					

Recommendations of the President's Scientific Research Board

In 1947 a series of reports were made on science and public policy by John R. Steelman, then assistant to the President of the United States and chairman of the President's Scientific Research Board. One of these reports, *Manpower for Research,* presented the viewpoints of the Cooperative Committee on the Teaching of Science and Mathematics of the American Association for the Advancement of Science on the effectiveness of the public schools in providing science instruction, particularly for the gifted student. The Cooperative Committee had been requested to submit its findings and recommendations for inclusion in the Steelman report. The following lengthy excerpt from this report presents another viewpoint on the organization of the science curriculum in the secondary schools.[9]

[9] *Manpower for Research* (The President's Scientific Research Board, *Science and Public Policy,* Vol. 4. Washington: Government Printing Office, 1947), pp. 85–90.

An analysis of the United States Office of Education statistics . . . reveals the fact that a majority of the secondary school students of the Nation are not continuing science education beyond general science and biology.

The implications arising from this fact are:

(1) The contribution which physical science can make to education is not provided beyond the elementary concepts treated in general science.

(2) It may be questioned whether the physics and chemistry commonly offered in the eleventh and twelfth years are appropriate for the purposes of general education.

(3) The low enrollment in physics and chemistry may be due to several factors:

(a) The present offering does not provide adequately for the needs of either the students who do not intend to study science further, or the science-talented students who are capable of rigorous work and do intend to continue in science.

(b) The crowded nature of the secondary school curriculum, which does not permit the displacement of other subject areas.

(c) The undue influence of college entrance requirements which commonly require only one unit in science.

(d) The lack of adequate equipment, methods and teaching personnel.

(4) The students being attracted to high school physics and chemistry may not be those who could profit most by a rigorous course in these subjects. Observation would indicate that many who enroll might better be served by a general course in physical science, while at the same time many able students who could profit are not guided into these subjects. This situation requires study of the methods and techniques desirable for the proper identification and guidance of talented youth.

(5) High schools usually do not offer training in the biological sciences beyond the initial course in biology, nor similar training beyond the initial courses in physics and chemistry. This would seem to restrict the opportunity available to youth with special interests and talents in the sciences.

There seems to be justification other than expediency in suggesting a physical science course. Such divisions as physics and chemistry are, in the final analysis, more or less arbitrary divisions of organized knowledge, which are meaningful to the specialist but may not be particularly intelligible to the student who will not make a career in science. . . .

Much more use should be made of the history of science with

its adventure and dramatic action, which appeal strongly to young people's interests and arouse their imagination.

"Scientists are then thought of as living men, facing difficult problems to which they do not know the answers, and confronting many obstacles rooted in ignorance and prejudice. In imagination, the students watch them at work, and look particularly for the methods which they use in attacking their problems. They see them, in Pasteur's words, 'constraining themselves for days, weeks, even years, trying to ruin their own experiments, and only proclaiming their discoveries after having exhausted all contrary hypotheses.' Thus the methods of science are taught as instruments which men have created and used to solve some of humanity's most important problems. . . .

"Students trace the development of the view that we live in a world of natural laws, or orderly cause and effect, not a world of chance or arbitrary action. They observe the growth of faith that human intelligence, using the scientific method of inquiry, can discover the laws of nature and so bring the physical world increasingly under man's control. They also see that science has given man the basis of many of his highest hopes for a better world. For science not only makes progress possible, it also sets new goals for man to work toward. From the scientific point of view, disease, poverty, ignorance, and inequalities of opportunity are not evils to be passively accepted. They are evidence either that we have not yet solved some problems which can be solved, or that we have failed to apply the scientific knowledge which we already possess. . . .

"Most boys and girls . . . are now able to develop a conception of a natural universe, operative according to laws, and of themselves as parts of that universe. When once this pattern of thinking has been well established, other facts and principles are fitted into it as students continue to learn."*

Science Education for Specialists

The above discussion does not in any way suggest a weakening of the programs in the specialized science subjects, such as physics and chemistry. Rather, with an adequate program of selection and screening, these courses will be free to serve their real purpose of further stimulating and guiding our potential scientists.

"A broad education is the product of broad interest. If the student has a real and lively interest in a field, he will educate himself in that field; he will seek to read all that he can find about it, he will talk about it with his fellow-students, he will approach his instructors, and, most important of all, he will reflect upon it. And no such interest will operate in a single

* Educational Policies Commission, *Education for All American Youth*, National Education Association, Washington, D.C., 1944, pp. 131 ff.

compartment; it will reach out and include a number of related fields."*

The number of specialized science courses which can be offered in a high school is determined primarily by the personnel of the high school, by the number of students qualified by interest and talent to profit from such courses, and by the financial resources available for the development of proper facilities and equipment.

Some of the larger school systems have made certain provisions for the specially talented. One city, having several high schools, has designated one a technical school, one as a manual arts school, and one as a college preparatory school. These schools in reality serve regions of the city and therefore provide broad education facilities, but simultaneously they serve the entire city in their particular fields of specialization. Students who "just go to school" will probably go to the school in their community; but students who have a desire to explore particular types of specialized training will attend the one school in the city system which provides it.

"The education of mentally gifted children as a separate group is one of the relatively newer programs in public education."† "Major-work" or "Honors" classes are set up by some cities for the purpose of providing the gifted child with the opportunity to develop his special talents and interests to an extent limited only by his own capacity. Such class groups meet with specially qualified teachers who are sympathetic with the idea of developing student talents to a maximum extent and in classrooms equipped to allow the student freedom for individual investigation. These classes meet in the same building with other school groups and therefore their contacts with other children are not severed.

In the very large cities, where there may be a sufficient number of students whose special talents have been identified by the time they have completed the 8th or 9th grade, it will be possible to establish specialized high schools. Students are selected for these schools on the basis of interest and ability. "Since the specialized high school, in order to achieve its purposes, is so uniquely dependent upon enrolling students who can profit by its special offerings it tends to perfect its instruments of selection."‡

As an example, the Bronx High School of Science in New York City has used a "Science Fair" and "Science Congress" for

* Board of Education of the City of New York, *Specialized High Schools in New York City*, 1946, p. 19.

† *Annual Report* of the Superintendent of the Cleveland Public Schools, Cleveland, 1945, p. 72. The comments on the Major Work program which follows are based upon this report.

‡ *Specialized High Schools in New York City*, p. 33.

The "Advanced Science Problems" class at University High School, University of Illinois, provides opportunity for maximum development of science-talented youngsters through provisions for independent research on approved problems. (Courtesy of University High School, University of Illinois)

stimulating and discovering science-talented children in the elementary schools. In the case of the Science Fair, children are encouraged to exhibit their projects and experiments; these are judged and prizes are awarded. In the case of the Science Congress, young people are brought together for pupil demonstrations and talks. The speakers and demonstrators are selected from students of the elementary schools after study of a large group of applications. These pupils are presented a Science Congress Certificate, which later becomes a factor when their application for admission to the school is considered.

In the first of the three special types of organization, described above, for dealing with the specially talented youth, we have a situation in which the student may attend classes such as English and social studies together with students from varied curricula; but he has opportunity in this school to attend rather highly specialized classes in particular subjects, such as botany, zoology, physics, and chemistry. In the second type, students of a high order of ability and of varied interests pursue the phases of their

general education as a special group. They are provided abundant opportunity to develop their individual talents. "Teaching to meet individual needs"* can be superbly done under this plan. In the third type, the specialized high school, the entire school is fitted to the needs and purposes of a particularly selected group of students with common interests and talents.

Some of the smaller high schools provide for the needs of students with special talents by plans such as the following:

1. Offering only the specialized science courses. This means that the general students are given little if any consideration.
2. Offering only the generalized science courses, with special projects, reports, and teacher assistance for the talented students. Some schools use correspondence courses in the specialized fields as additional work for the talented students.
3. Offering only generalized courses and stimulating the talented students through science club activities.
4. Some adaptation or combination of the plans outlined above.

Unfortunately, many of the schools, small or large, provide little or nothing to recognize the needs and interests of either the general students or those with special talents. The courses are taught and the students can take them or leave them. As a result, many students drop out of school or graduate without the valuable contribution which science can make to their education and their future careers.

One of the differentiated programs recommended earlier should be adopted by each secondary school. Too often the traditional high school in its program of mass education has failed to define the purpose of its science curriculum, to identify and guide able students, and to promote the kind of specialized and stimulating work which the talented youth needs.

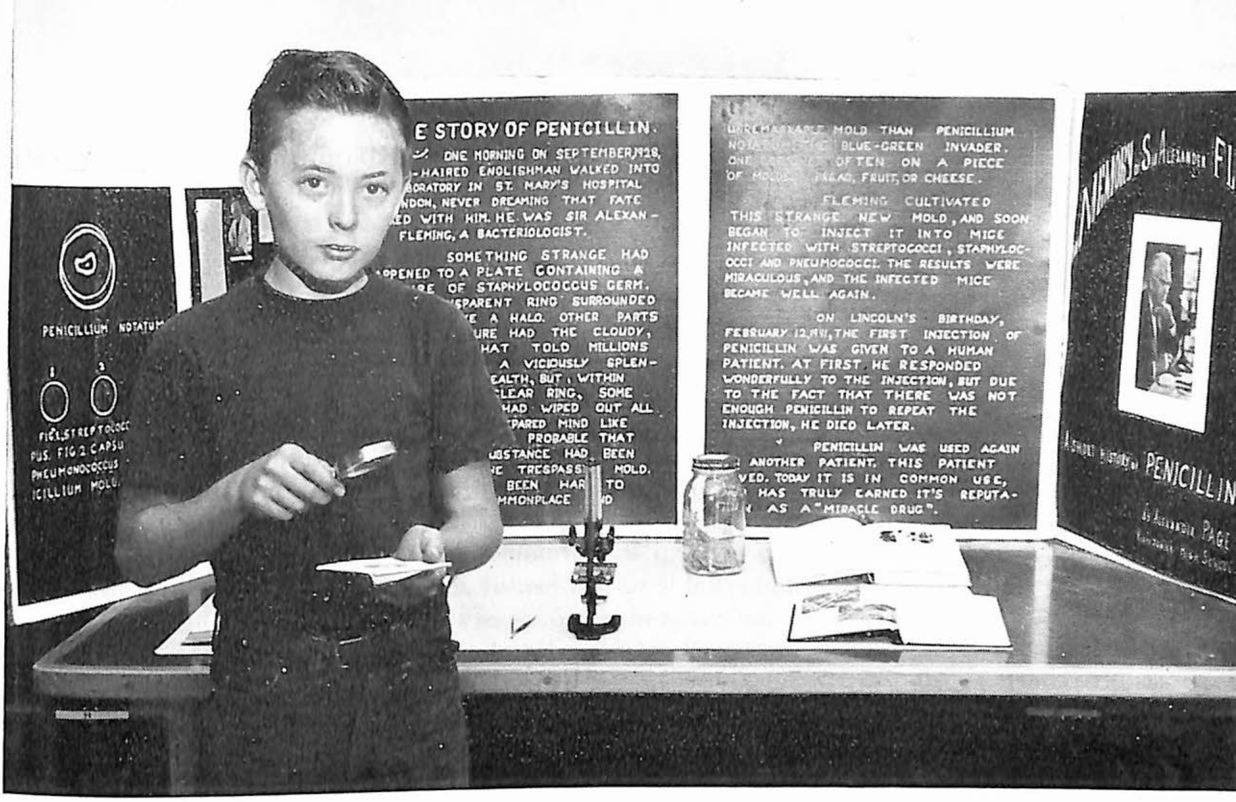
IDENTIFICATION AND GUIDANCE OF TALENTED

To meet the needs of specially talented youth the school must have a continuous program of identification and guidance.

Rapid promotion and permission to carry extra studies are common attempts to meet the needs of talented students. Such programs are often inadequate and seldom do little more than keep the pupil busy by providing a greater number and variety of activities. Extra studies are often taken because they fit into the schedule of free periods of the student and not because they fit into the well-developed educational program for him.

The discussion and recommendations regarding selection and identification appearing earlier in the section on science and

* *Annual Report* of the Superintendent of the Cleveland Public Schools, p. 72.



Science-talented students can often be located in the elementary and junior high grades. Identification techniques of fair validity now exist for early selection of such students. (Courtesy of San Diego County Schools)

mathematics education in the elementary school continue to be pertinent. The cumulative record file, which includes anecdotal statements regarding the interests and capabilities of pupils and a record of school progress, must be continued through the secondary school.

A few of the students with aptitude for science and mathematics will have been identified in the elementary school and others will be identified through the many procedures now used for evaluation in the ninth and tenth grade science and mathematics courses.

The end of the tenth grade is a desirable time for the use of special techniques for the identification of specific aptitudes. Science aptitude tests have been developed which in conjunction with other measures, such as vocational interest inventories, will help to locate the student who should be advised of opportunities for success in fields of applied science and research, mathematics, chemistry, physics, botany and zoology.

It should not be implied that students should be assigned to certain specialized courses; rather the counselor should use such items of information as excellent performance on aptitude tests to break down the prejudice that may exist on the part of the

student against certain courses and to convince him of his capacity for profitable participation in these specialized courses.

An example of an organized program of selection is that carried on in New York City by the Bronx High School of Science.* They base their selection on:

1. A written test.
2. A study of previous school record.
3. The recommendation of the lower school authorities.
4. A personal interview.

The written test consists of CAVD† material carefully assembled by Dr. Irving Lorge, head of the Department of Psychology at Teachers College, Columbia University. In the course of years, this test has been refined so that it can be regarded as a valid and reliable instrument of selection. Two-thirds of the applicants are selected on the basis of the written test together with a study of the school record and the principal's recommendation. The remaining one-third is selected on the basis of a personal interview by a group of trained interviewers. The test and the selection procedure are designed to identify graduates from the elementary school who are academically able and interested in science and mathematics, with a view to making science and mathematics the bases of their future careers.

The location and identification of students talented in science and mathematics should be continuous through the entire secondary school program, and the counselors should take seriously the obligation to aid these students in obtaining satisfactory programs of study in high school and admission to colleges best suited to their needs. Counselors and teachers should encourage talented students to attempt to gain entrance, advanced credit, and scholarships in such colleges or universities.

In the six annual Westinghouse Science Talent Searches conducted by Science Service, students from certain schools have repeatedly been selected for honors in numbers out of proportion to their school populations. For example, one school with a registration of about 2,000 has had from 1 to 4 "winners" in each of the six annual competitions, together with a total of about 30 honorable mentions. Another school has had at least one winner in four of the six annual competitions. Both schools referred to screen their students carefully for science interest and talent and provide them with a curriculum of 4 years of science study and laboratory work in addition to a 4-year sequence in mathematics. Included in the curriculum are also 4-year sequences in English and in social studies, together with the other subjects usually found in the 4-year high-school course.

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* *Specialized High Schools in New York City*, pp. 225–226.

† Reading comprehension, arithmetic reasoning, knowledge of vocabulary, and ability to follow direction.

A number of interesting ideas are contained in the section of the Steelman report just quoted. Based upon the successful experience of schools which have tried them, these ideas should receive the most careful consideration of every science teacher.

The report questions whether physics and chemistry courses are appropriate for the purposes of general education and suggests that such courses may not be particularly intelligible to the average student. Is this point valid? Is a physical-science course comparable to the general biology course a more appropriate offering for general-education purposes?

The report recommends the inclusion of material from the history of science. Will students learn from the history of science the nature of scientific research and the conditions required for the scientific acceptance of an observation as factual? Is the history of science a useful aid in the development of scientific-mindedness and a scientific point of view toward the physical world and man's problems?

The report suggests that specialized subjects be reserved for science-talented students and that a rigorous program of screening be used to select students who should take such courses. Is this concept of a general-education science program for all, coupled with a specialized science program for selected students, tenable? Is it practicable for the average school?

Are the four provisions used by the smaller high schools for meeting the needs of science-talented students the only alternatives? Can the organized program of selection of science-talented students carried on by the Bronx High School of Science be adapted to other schools? To small high schools?

These are among the questions which each science teacher and each high school staff should raise and for which they should secure workable answers. The standard programs of general science, biology, physics, and chemistry were developed in former years when the schools enrolled a different and more selective school population than they now serve. It is of the utmost importance that widespread thought and experimentation be given to the reorganization of these standard courses so that both modern general-education needs and the specialized needs of the students who have high aptitudes for science are better met. Both the average student and the gifted student may be suffering from an organization of science courses that has outlived its usefulness.

A RECOMMENDED PATTERN OF SCIENCE COURSES

It is risky to propose any single pattern of science courses as being preferable to all others. But there are certain criteria for a pattern of science offerings which will, at least, provide the setting for sound and developmental learning experiences in science.

First, it is useful to assume that there are some science learnings which are of such fundamental importance to personal and social life that they may legitimately be required of all learners. What these might be, specifically, would engage us in endless controversy. What specific facts, principles, skills, and habits are essential or even highly desirable for all youth is a question without an answer—for youth vary and their needs vary. But if we keep in mind the primacy of the *skills* of learning, investigation, and critical thinking in our hierarchy of educational goods, and if we recognize the psychological advantages of planning the details of our instruction with our students, we can side-step the question of details and deal with broad areas of indisputable importance in the lives of all Americans today. Any number of listings of these could be made which would vary in their details and emphases. But the proposed four-year sequence of topics which Brandwein suggested (see pages 144–146) will suffice for our present purposes. The point at the moment is that we can assume that certain broad areas of personal and social significance should be studied by *all* students and should therefore be parts of *required* courses.

Second, the required courses should be organized around basic and important areas, issues, and problems. They should be psychologically structured rather than organized around the internal logic of a subject field, a logic divorced from the realities of life.

Third, although the work should evolve from the common purposes of the student group, the teacher must remain responsible for seeing to it that the students make intensive, sustained, and intellectually rewarding investigations of the fundamental facts, theories, and principles of the disciplines that relate to the problems being studied. In short, our third criterion demands that the teacher assume the responsibility of helping his students to study and work in an increasingly disciplined fashion. No major unit of work should be terminated until the students have organized their thinking on the basis of the observed facts and generalized their learning experiences into clear-cut patterns of thought that can form the basis of more reflective thinking, additional learnings, and sound action in personal and social life.

Fourth, the required courses—what they are called is of small consequence—must be fitted into an already tight curriculum of other important learnings in the social sciences, humanities, arts, and so forth. We cannot demand the lion's share of instructional time. But, if the work we offer is of demonstrable worth, we can legitimately work for the time when a minimum of two years of science will be required for every high school youngster. The science we are here discussing is not a subject "from which nothing follows," to quote Whitehead again. It is science that forms an integral part of the life of the child and of the society in which he lives and must play his part. Two years of intensive analysis of these problems from a scientific point of view are by no means excessive. And the administrator who could properly object to two years of "textbook" science of no clearly seen value to all the students will see the

necessity of a minimum of two years of functional science, if the courses are well conceived and well taught with demonstrable results.

If the general-education program of the school is organized around core or common-learnings courses, and science plays the part it should play in them, then, of course, the amount of time devoted to required science courses will depend on the larger administrative question of how much time to devote to the entire core program. But the science teacher should insist that real and fundamental science activities and learnings are carried on in the core program for each of the years it is taught—either this, or separate courses for at least two years.

As a matter of fact, if the science instruction is actually focused on living problems and is dynamic, democratically conducted, and taught with skill, enthusiasm, and responsibility, the matter of required courses becomes somewhat academic. We are familiar with a number of high schools where only one year of science is required but where it is necessary to limit the enrollments in the elective sciences because of student enthusiasm! And these are not "easy" science courses in the usual sense of the term. The teachers, without exception, require substantial and responsible work. But it is meaningful work—meaningful to the students who help plan it and who savor the satisfactions of intellectual work and work well done.

Our fifth, and last, criterion refers to the elective courses that should be made available to all who care to take them and can profit from them. It is this: Every school should offer intensive instruction in specialized sciences such as physics, chemistry, zoology, and botany (or perhaps advanced biology) on an elective basis. In the smaller schools, not all may be offered, or it may be necessary to alternate the years in which these courses are offered. But qualified students who are willing to work to the limits of their capacities should be offered a chance to take four years of science if their interests and abilities so indicate. These specialized courses should be organized around the fundamental principles and generalizations of the fields themselves. They need not—they must not—be rote or textbook-dominated experiences. But they should provide the interested and qualified student the opportunity for intensive and disciplined study of the disciplines of science as such. They can well be courses of college caliber in the best sense of the term. If they are, arrangements should be made for the students who take them to by-pass, on evidence of proficiency, the equivalent courses when they go to college. The specialized courses, like the general-education courses, should stress independent thinking and investigation. They should utilize a wide variety of references. And they should deal inductively with the principles of the science, as well as provide sufficient opportunities for the students to demonstrate that they can deduce and apply their learnings both verbally and practically.

In addition, any school might provide such additional courses as student interest and staff time make possible. Courses in geology, astronomy, meteorology,

and applied sciences, such as photography, mechanics, aviation, agricultural science, and so forth, are important and will add immeasurably to many students' enjoyment and profit from school work. How far the school goes in offering such elective subjects should depend entirely on the interest expressed by students and the taxpayers who must pay the bill. *But such courses should never take the place of a certain minimum of required courses for all students and additional basic science electives for the qualified.*

This recommended general program is shown in tabular form as follows:

A RECOMMENDED GENERAL PROGRAM OF SCIENCE FOR HIGH SCHOOLS

Required of All Students	*Electives Available for Qualified Students*
Minimum Two years of laboratory science centered in problems pertinent to general education values (four years if the seventh and eighth grades are included). One year of the required sequence might be in the life sciences and the other year in the physical sciences. Or the work for both years might be developed on the basis of functional units without regard to the distinction between physical and biological topics.	*Minimum* Physics, chemistry, zoology, and botany (or advanced biology). *Recommended* Additional courses in applied or hobby fields; for example, photography, aeronautics, astronomy, geology.

SUMMARY

The typical program of science courses includes general science, biology, physics, and chemistry. In addition, many schools offer applied science courses such as aviation science, photography, and earth science. Valuable as these applied sciences may be in developing specific skills and understandings, they do not have the inherent possibilities that the basic sciences do of developing intellectual maturity. They should not, therefore, replace science disciplines in a student's program.

But the traditional pattern of general science, biology, physics, and chemistry is not necessarily the best organization of basic sciences for general education or for the specialized needs of science-talented students. General science has probably outlived its usefulness and offers little more to the student than he typically gets from his elementary school studies and the information he secures from TV, radio, newspapers, and magazines. The majority of students take both general science and biology (see Chapter 1). It would seem logical therefore to remove the life-science phases of present general-science courses and convert this course to one in physical science. It would seem desirable to require all students to

take two years of science. One of these years might be in biology and the other in physical science. Or it might be better to denote both years as general science and to develop content and activities around areas of clear value for general-education purposes.

Whatever the pattern of organization of required general-education science courses may be they should be developed for their functional values for daily living and for their potential in developing maturity in young people.

In addition to required courses for general-education purposes, every school should provide elective courses for the students who have special talents for science. Each school should develop a procedure whereby the students with special aptitude for science may be located and given stimulation, guidance, and instruction suitable to their high potential abilities. These students should be encouraged to enroll in such specialized sciences as physics, chemistry, zoology, and botany (or advanced biology). These courses, although specialized and enrolling only interested and able students, should provide the opportunity for intensive and disciplined study of sciences as disciplines. They should stress independent thinking and investigation and be organized around the fundamental principles and generalizations of the fields.

Finally, every school should offer, to the extent that student interest, staff availability, and finances permit, a range of other science courses and applied science courses such as geology, astronomy, meteorology, photography, and aeronautics. These courses might be of primary value to the students who are not interested in going to college but who wish to take more science than the two-year required sequence.

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7

PREPLANNING FOR BETTER TEACHING

There are three major approaches to curriculum construction in the field of science. These may be categorized as the "field-covering" approach, the "generalizations" approach, and the "problem" or "functional" approach. An examination of teaching practice and of textbooks and other curriculum materials, including evaluation instruments, reveals that most teachers offer knowing or unknowing allegiance to the field-covering approach; a minority utilizes the generalizations approach; and a small but rapidly growing group attempts a functional or problem approach.

The field-covering approach is the formally organized textbook treatment of science content that has been described in this book as the "old" in science teaching. The generalizations approach, together with the problem approach, represent, in general, what has been called the "new" in this book.

If we could assume that teachers adopted an approach because they had subjected it to critical analysis in the light of clearly seen objectives, we might also assume that experience and judgment had found the field-covering approach to be the most satisfactory. Unfortunately, the majority of science teachers have not critically examined the assumptions underlying their offering or the criteria which their objectives and curricula were intended to meet. Rather, they have been prone to accept whatever emphases and organization of content that their training, tradition, and present textbooks and standardized examinations have dictated. Furthermore, as was shown in Part II, there are both theoretical and empirical grounds for questioning the validity of the field-covering approach despite its wide use in science curricula today.

This chapter is designed to provide the science teacher with a procedure which will assist him in organizing science content and activities within the framework of the problem-centered or functional curriculum. Before describing this procedure, which is basically a technique for developing "resource units" (a term which will be explained later in the chapter), it is desirable that we critically examine the nature and orientation of the three general types of curriculum. Earlier chapters have provided some delineation. The following sections offer further clarification of the characteristics of these three approaches, together with some observations regarding their rationales.

THE FIELD-COVERING APPROACH

Basically, the field-covering approach to the development of science programs, as most commonly accepted, is an attempt to survey the complete archives of science and to select, judiciously, "fundamentals" upon which may be built later studies leading ultimately to mastery of the field and to research specialization. It is a "logical" and "descriptive" organization of subject matter presumably basic to further study in the area.

The field-covering approach to the development of a program of science for young people encounters difficulties today not faced one hundred, fifty, or even ten years ago, for the fields of science have been expanding rapidly. The basic sciences from which high school physics, chemistry, and biology are derived have developed considerably and have produced hybrid offspring such as astrophysics and biochemistry. Obviously, the job of "sampling" these fields and of making selections of what is fundamental is a tremendous one.

How, then, do we decide what samplings of "fundamental" materials to take from the wide range of scientific studies? Is it less "fundamental," for example, for a student to know something of the nature of histamine and the physiological effects of the action of histaminase on histamine than it is for him to know the names and actions of ptalin, pepsin, and trypsin? The former has probably never been presented in a high school textbook, and the latter has been included in an almost identical fashion in practically all biology textbooks. Few authors or publishers would omit discussion of the digestive enzymes in a biology textbook and expect the necessary sales to merit publication in the competitive market. Why? What *is* fundamental? The digestive enzymes will continue to function or malfunction regardless of whether students know their names and call this knowledge scientific learning. But the field of hypersensitivity and the enzymatic action of histaminase in the destruction of histamine effects in the body may lead a young person to understand something of one type of hypersensitivity and could possibly lead to the betterment of his health through more informed cooperation with physicians. It probably would not, however. We have purposely presented two rather educationally meaningless bits of scientific data to address a point. Which, if either, set of data is fundamental? Which shall we select in

our sampling of the vast field of biological sciences for inclusion in high school instruction? Why has one been selected rather than the other?

The last question is easy to answer. When the earlier textbooks were written, scientific research had produced data regarding the digestive enzymes but none on many of the other enzymes involved in body metabolism. The earlier texts included digestive enzymes as part of what was then considered the fundamentals of the broad field of biology. The purpose of science instruction in those days was primarily preparation for college. And preparation for college was considered to consist of covering the basic elements of a field.

The idea of covering the basic elements of a scientific field was far more feasible in the late 1800's than now, simply because there was not so much to cover. The field-covering pattern for the teaching of each science was firmly established many years ago, and the details of that coverage were established almost as firmly. As new data were made available by the advance of science, these, too, slowly percolated into the high school textbooks. But they seldom replaced materials established as desirable in the early days of science teaching. The books got larger as the newer facts were added. But the idea of removing older material and replacing it with newer material ran counter to the still-existing notion that the "basic elements" of a science should always be retained. The question of what is really basic has too seldom been considered. Habits and practices of the past are often retained from sheer inertia rather than because of demonstrated value. So much of the scientific data which are truly fundamental to our technological age, and which might be valuable to the personal well-being of young people, are rejected simply because there is not room in the texts for these and the older materials as well. Such newer and possibly more valuable data are seldom even found in the introductory general-education courses of college science, and for the same reason. These data are generally found only in courses designed for professional training in engineering, medicine, and similar professions, and in the advanced courses designed for research workers.

We are by no means objecting to providing a grounding in the basic principles and fundamental data of the sciences. It is clear that the high schools must accept the responsibility for providing grounding in the organized sciences for all young persons who plan to continue their scientific studies in college or who may elect science courses for any reason whatever. But specific facts should not be confused with basic principles and fundamental data. The point at issue is whether the field-covering approach, dealing as it does with a necessarily superficial sampling of organized scientific data, constitutes the most desirable science program either for general education or for the more rigorous preparation of the student who may become a scientist. The question is whether a more functional and humanistic selection and organization of content and experiences is superior to the classical pattern for general-education purposes and for college preparation as well. The field-covering approach is basically a vocational ap-

proach to the building of a science program. It results in a sequence of descriptive courses of probable value for the technician but not for the potential creative scientist or for the average citizen-consumer. And, at best, it tends more to produce a walking textbook and skilled technician than an informed and critical-minded person who knows well what he knows and the basis of whose knowledge is the methodology of science. It tends to produce people who may know the "whats" and "hows" in a superficial sense but not the "whys" and the "wherefores."

If the critical data presented in Parts I and II of this book are reasonably valid, why is the field-covering approach still the dominant approach to the building of science programs in the secondary schools today? It is dominant for the following reasons: Teachers who work in the secondary schools receive their college training in undergraduate science classes which generally emphasize descriptive facts rather than methodology and critical thinking. The teachers, therefore, tend to teach and to select curriculum materials focused on descriptive organization without reference to meaning in the lives of young persons and society or emphasis on the process by which scientific data are obtained and used. This tends to stereotype content and organization into a pattern which many teachers and textbook writers seem to think of as defining and delimiting the possible science offerings for the secondary school. Of course, after new data become available—and usually after an unconscionable time—these may be added to the high school textbooks and school offerings. But they are added only as descriptive content, presented without the methods by which they were wrested from nature. And seldom is anything taken out. So the books get bigger and bigger. And the teachers race faster and faster to "cover" the textbook. The students do their best to keep up, often developing feelings of harassment and frustration. The end of the semester arrives, and the students feel that they have "taken" physics, or biology, or chemistry, or general science. Retention tests, as well as general observation, disclose how little the class has really learned. Sometimes, the teacher cannot quite finish the book. And he has strange guilt feelings. Why? In a very fundamental sense, the more he strives to cover the book, the less he is likely to teach his students the meaning and use of the powerful tool that is the methodology of science.

It should be clear that the field-covering approach does not, and really *cannot*, cover any field of science. It is a sampling from the past, laid out in a tightly organized plane of time, added to occasionally as new data are made available, and taught as if the course were a steeplechase and the lives of the youngsters depended on their completing the set number of jumps the textbook demands. It continues to be used largely because it is relatively simple. Comparatively few science teachers secure the necessary breadth and depth of preparation in the sciences to make a break from the field-covering approach. It is possible for a teacher with little background in science to teach from a textbook, keeping ahead of his students. But to utilize the generalizations or needs approach to

the teaching of science, a teacher must leave the textbook behind. He must know his science, what it means in the lives of young persons and society, how to organize his materials for effective learning, and how to work with the diverse kinds of young people he will have in his classroom. All this is much more difficult than teaching the same facts year after year after year from the same old notes and from a descriptively organized textbook.

THE GENERALIZATIONS APPROACH

The generalizations approach to science-curriculum construction was first presented in the Thirty-first Yearbook of the National Society for the Study of Education in 1932. It was presented as a reaction against the sterility of the field-covering approach. Research and experience had shown that the field-covering approach resulted primarily in encyclopedic learning of discrete facts that were often meaningless and unrelated in the student's mind and generally retained only long enough for verbalistic employment in the artificial hurdles of paper and pencil examinations (see Chapter 4). It was believed to be highly doubtful whether it was even the best method of providing basic training for the relatively few who might be expected to become scientists after college work in their field.

In the generalizations approach, those major generalizations, or "big ideas," of science that have influenced or are capable of significantly altering men's thinking and acting are the subjects of study. Content and experiences are selected to provide a meaningful and supporting framework for the generalization. The adoption of this approach would be a major advance in science instruction (see Chapter 5 on the nature of generalizations and the general process by which they are learned). It would force a re-evaluation of science offerings in terms of significant major laws and concepts. Furthermore, it would mean that the single criterion of basic training as preparation for ultimate specialization would be abandoned in favor of criteria of human significance, including, of course, those principles that are really fundamental to the organized discipline itself. Theoretically, it would mean that important and established major scientific truths would be adduced and science content would be organized so as to provide experiences leading inductively to functional understandings of the generalizations. If this inductive approach were rigorously followed in practice, facts which had been discrete and apparently unrelated in the field-covering approach would be directed developmentally toward increasing the student's appreciation of major natural phenomena and laws. The attempt to cover myriad facts would be abandoned. There would be less teaching *about* science and more teaching *of* science and its methods.

This approach has seldom been really tried. It has been too easy for textbook writers and teachers to raise the banner of a generalizations approach and then to continue with the same organization and content formerly used, pausing only

long enough to reshuffle and dump unassorted facts in a disorderly heap around each major generalization they were purporting to teach.

Even when an intellectually honest attempt has been made to develop science curricula by the generalizations approach, serious inadequacies have become apparent when the approach has been used to construct a general-education program. The generalizations approach is still a circumambulation around the criteria of human significance (personal and societal needs) from which the generalizations should be drawn for general-education purposes. It is too easy to accept a verbalism of the generalization and an assortment of facts that really contribute little to inductive and deductive learnings. Such learnings are required before a student can generalize from his experiences and develop a real knowledge and command of the generalization itself. The generalizations posited in the Thirty-first Yearbook of the National Society for the Study of Education were verbalisms of natural laws and phenomena, with little documentation or support to show their actual worth to young people or society (see Thirty-first Yearbook, Part I, pages 53–54). Most of them can be supported, but that task was left to the teacher or textbook writer.

The consequence was that most teachers got lost in the verbalisms and never found their way to the problems and concerns which were supposedly the core from which the generalizations drew their meaning and educational value. Thus, ignoring the prime factor of human worth and accepting the generalizations presented in the *Yearbook* as *the* generalizations (which the Yearbook Committee never intended), a considerable number of science teachers began to teach these laws and principles as ends in themselves.

Whether or not this practice could be defended on the ground that the laws had educational worth, it must be considered psychologically indefensible. Even the scientist does not learn laws and generalizations in the abstract, nor does he attack a generalization directly. He encounters a problem that is challenging and real to him. In the process of scientific analysis, he arrives at certain tentative conclusions. As he works on other problems of a similar nature or containing similar elements, he finds the same factors operating, and similar conclusions are perforce reached. Ultimately, he has experienced a phenomenon in so many situations that he feels safe in stating a generalization or principle that apparently holds true under certain specified conditions. (More commonly, of course, this inductive development of scientific principles rests on the cumulative activities of many scientists.) Here, then, is the origin of a generalization. It grows out of a practical, or at least a real and nonacademic problem, that appeals to an individual or a group emotionally and intellectually as worthy of investigation. Once the generalization is made, it has value, not in and of itself, but because it can be used for control and prediction in solving the problems out of which grew similar problems. A generalization is a broadly applicable—a generic—truth.

We do not suggest or imply that learning must be delayed until a student

fortuitously encounters problems in which the generalization operates. Nor do we suggest that a student must retrack the tortuous path by which a generalization came into being (although, indeed, the historical approach has considerable merit). But we do assert that generalizations or principles or laws—call them what you will—must be inductively learned as learners tackle problems that are significant and in which the generalization is operating.

Teachers generally have failed to understand the real significance of a generalization in science—and therefore the generalizations approach to the teaching of science. A psychologically sound approach to the understanding of a generalization starts with a problem that the student accepts as worth his attention. This must lead inductively to the generalization if it is to have more than verbalistic meaning to the student. Science is of value because it gives us power to predict and control. Generalizations are merely tools for handling problems and situations with assurance of predictive and controlling power.

THE FUNCTIONAL OR PROBLEM APPROACH

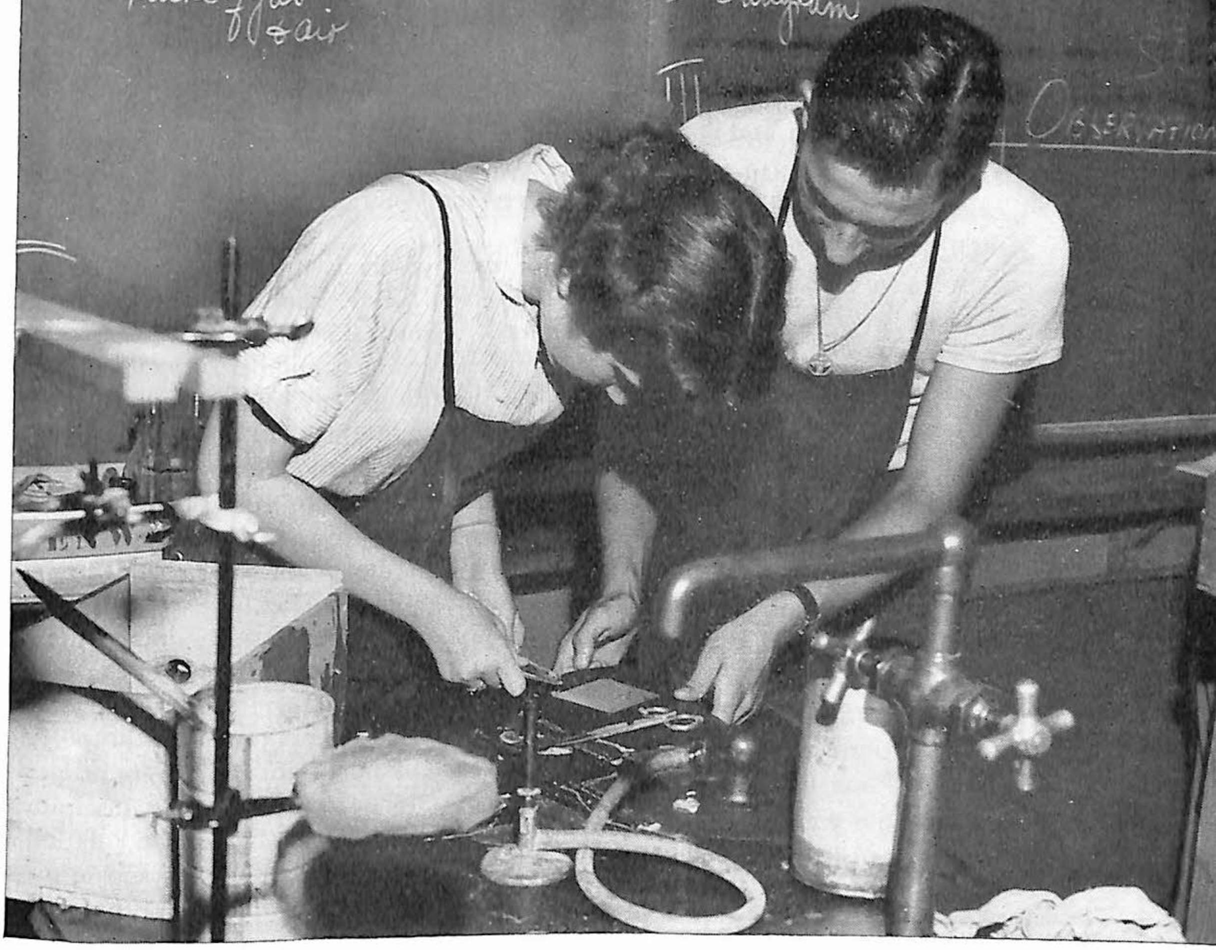
The functional or problem approach to curriculum development in science teaching is a logical outgrowth of the generalizations approach and is basically an insistence that the criteria for the selection and organization of content and learning experiences are to be found in democratic values, social problems, and the problems and situations with which young people must or will choose to deal. It considers generalizations not at the top of the pile of educational significance but as useful knowledge—tools with which to resolve problems of meaning. It accepts science, moreover, as a way of thinking and acting, a procedure, and a major philosophy, as well as an organized body of knowledge discovered and validated by that procedure and accepted because the philosophy demands pragmatic proof rather than authoritative dicta. Further elaboration of the problem approach is not necessary here, for most of this book is devoted to a developmental treatment of the method and its justification.

We have already indicated that the great majority of science teachers use the field-covering approach; they teach directly from the textbooks they use with little or no modifications of the descriptive treatment the textbooks provide. But do teachers accept the basic philosophy of the problem approach?

With the cooperation of the Research Division of the National Education Association, the writer conducted a study in 1940, for the National Committee on Science Teaching, of the opinions of science teachers throughout the United States on their responsibility to young people and to society.[1]

We have listed on the following two pages the findings from this study that bear on the question we have raised.

[1] R. Will Burnett, *The Opinions of Science Teachers on Some Socially Significant Issues* (New York: Bureau of Publications, Teachers College, Columbia University, 1941).



Teachers using the problem approach consider both facts and generalizations as means with which to achieve understanding. The approach assumes that both factual knowledge and generalized insights will best be developed through an inductive attack on significant problems. (Official photograph, Board of Education, City of New York)

1. A large majority (more than 80 per cent on each specific question asked) expressed the belief that a major responsibility lay in facing the problems and interests of young people and society and in bringing their specialized ability and their subject to bear on these problems and interests. Science teachers do accept the functional approach in theory.
2. In spite of this professed belief, the teachers of science throughout the nation were for the most part avoiding several controversial areas which were important to young people and society. They were avoiding the very areas they felt to be of the highest instructional value.
3. They were avoiding these areas in large part because they knew too little about them to handle them adequately. These were science teachers, trained in science to lesser or greater degrees. But, somehow, the science courses taken in college

did not provide the understandings necessary for these teachers to instruct young people in these problem areas, although the teachers considered the issues in these areas to be of high instructional value.

4. Supporting data for the hypothesis that teachers of science are inadequately trained to handle important areas in which controversy exists was obtained. The teachers were asked to express their opinions concerning a number of issues selected by college professors of anthropology, philosophy, sociology, and science education as significant areas of human concern at least partly amenable to educational treatment through science instruction. The opinions of science teachers on these issues had no significant relation to their major fields. There were no differences between the biological-science, physical-science, and nonscience majors. (The one exception was evolution. Majors in biology gave significantly different opinions on evolution than those given by the nonbiology majors.) It made little difference whether these teachers had taken certain specified courses, such as genetics and anthropology, although some of the crucially important issues were properly within the province of one or more of these disciplines (questions relating to racial, ethnic, religious, and national prejudice, for example). Either no attention was paid in these courses to these important issues, or the opinions of the science teachers who took the courses were not affected by them.

The typical science teacher has been subject to preparation in science which has ignored, for the most part, training which would enable him to implement the function he believes is his in a democratic society. His training, the books and other curriculum materials he uses, the standardized examinations he gives, and certain college-entrance examinations that a small number of his students may face, all tend to force his teaching into a field-covering stereotyped caricature of dynamic and functional science teaching. The inertia of tradition (see Chapter 3) has impeded the development of really significant science teaching for the purposes of general education.

PREPLANNING TO ENSURE FUNCTIONAL SCIENCE TEACHING

The teacher is not to blame for the impediments that stand in the way of effective teaching. He cannot create his own college program or pull himself up by his bootstraps. But he can do what an ever-growing number of good teachers are doing. He can learn on the job and develop resource materials which will make it possible for him to utilize the problem approach with sound results, results that he can test and verify and compare with the results he obtains from a field-covering approach.

The following procedure has grown out of the considerable experience of good teachers throughout the country. It is simple—even obvious—but it works. It is suggested as a method of preplanning that should lessen the difficulties of teaching by the problem approach. It will provide optimum assurance that your science teaching will actually function in meeting the personal-social needs of the students.

The first step, and the most necessary one, in the functional approach to curriculum development is to retire from one's field of expertness for a little time in an attempt to discover those problems or areas of significance that are worthy of educational treatment. It is important for the teacher to search for such areas with the eyes of a responsible citizen and leader of youth rather than with the eyes of a subject-matter specialist. If we start with our discipline, and than ask to what needs, problems, and interests it may contribute, we automatically narrow our field of vision and circumscribe areas of human concern by the limitations of our own training, technical background, and experience. Our training in science may have placed blinders on us in terms of the larger real-life problems to which our expertness might contribute.

True, we must ultimately return to our field and search it for contributions, but let us start our thinking with human beings, their problems and concerns. Studies of youth and their needs, community analyses, problems reported by community, regional, and national organizations concerned with all aspects of human affairs should be explored critically for clarification of areas of importance.

The second step, once areas of human need and concern have been determined and carefully considered, is to set up objectives within the areas and to analyze the processes and content of science to determine those objectives that are possible of attainment through science teaching. Such objectives should be honest and real in that they arise directly out of real-life problems or situations. These may be felt personal needs of young people, including interests in the world about them. They may be needs that are "predicated" or suggested as real by experts and other mature persons or by organizations. They may be found in social conditions that need bettering. They may be found in human values and aspirations.

The third step is to make certain that the objectives of instruction are so stated that they are obtainable through the instructional process. It is not enough to indicate broad goals that seem worthy of attainment. One of the most venerable, most stressed, and least attained goals in science teaching is "to develop scientific-mindedness." This "objective" has rarely been attained, in large part because stated in this form it is unattainable. It cannot properly be thought of as an objective at all; rather, it is an area of predicated need in which objectives may be found. The goal of developing critical and incisive thinking and the skills of analysis and synthesis are eminently worthy of attainment. But they represent an area of need which must be broken down and the

objectives stated in behavioral terms—what a scientific-minded person does—which give keys to the method of attainment.

An educational objective is something like a military objective. A general might state that his goal is to win a particular battle or even the war. But the wish is only a pious hope unless it is particularized by clean-cut objectives which imply in their statement the procedures by which they may be realized. Specific military objectives designed to meet the general's broad goals might include the capture of a particular hill heavily fortified with artillery and machine guns, the encirclement of a body of enemy troops that had penetrated deep into the general's own line, and the blasting of ammunition dumps far to the rear of the enemy's lines. Each of these objectives are stated behaviorally or procedurally. They imply the procedures and equipment to be used to anyone trained in the art of modern warfare. The details still have to be worked out, of course, but we now clearly see the jobs to be done in order to achieve our broad goal of winning the battle.

The case is quite similar in education. To state that we want to develop critical-minded young people or to develop disciplined intelligence leaves us floundering. It is a magnificent aim, but it must be implemented by clear-cut objectives set in behavioral or procedural terms. Without this practical next step they remain lip-service objectives and are sooner or later forgotten in favor of factual recall objectives, which can more easily be taught for, attained, and tested.

The following is a list of sixteen possible objectives that, if realized, might contribute to attaining the large goal of developing scientific or critical attitudes and abilities. A briefer listing of seven of the objectives was presented in Chapter 1, together with an analysis of what each might mean in terms of instructional procedure. Because of the analysis provided in Chapter 2 (see pages 34–41) the following is presented without amplification. It should be noted, however, that each of the sixteen specific objectives which follow imply an instructional methodology. The reader can make his own analysis in a fashion similar to that done for the seven objectives which were listed in Chapter 2.

TEACHING OBJECTIVES DESIGNED TO DEVELOP CRITICAL THINKING

To Work with Our Students in Such Ways That They Increasingly

1. Discover problem situations
2. Delimit problems into workable and procedural proportions
3. Develop critical hypotheses
4. Secure relevant, authoritative reference data expeditiously
5. Secure experimental or observational data critically and expeditiously
6. Recognize the bases of authority
7. Work cooperatively
8. Recognize personal bias and consider it in making judgments

9. Allow ascertainable facts to speak louder than prejudice
10. Communicate effectively and with accuracy
11. Recognize the limitations of both data and conclusions
12. Reopen issues when new data are available
13. Recognize the approximate nature of even scientific truth
14. Recognize the applicability of scientific methods to many nonscience problems
15. Recognize the universality of cause and effect relations within the framework of probability (the "uncertainty" principle)
16. Recognize the limitations of scientific methods particularly when applied to areas where control is difficult and where contingencies and imponderables are numerous

We will doubtless disagree on what should be included in the list of suggested objectives and what should be omitted from it. But we now have specifically determined objectives which we can accept and teach for, or reject as we choose, whereas, if we merely stated that we wanted to develop scientific-mindedness, we would have no basis for curriculum construction or for teaching. This third step is, therefore, imperative if sound instruction is to obtain.

Fourth, it is useful to separate "pervasive" objectives from "content" objectives. Pervasive objectives are those which are real and important enough (the list above states pervasive objectives) but which, generally speaking, are not best taught as a unit or area of focus. They are objectives which must be considered pervasively throughout curriculum construction and teaching. Understanding of these objectives may occasionally involve focal treatment, it is true, but generally they are concerns which, if recognized and taught for, permeate or pervade many or all aspects of the work.

For example, cause and effect relations should be understood emotionally and intellectually by every citizen in a democracy as applying universally, from the falling of a stone to a global war. (This remains true even within the framework of the "uncertainty principle" of modern physics.) Naturally, we would not consider our work done if we discussed only the universality of cause and effect relations. Every unit of work, every item of consideration in our science courses can be directed in such a way as to cause the learner to experience the fact that all natural phenomena are causally determined. Though repeated experiences the learner may come to look upon cause and effect relations as applying universally. He will thus have arrived at a generalization of great significance. He did not "learn" it by discussing it; he arrived at it through many experiences in which he saw causation operating.

Fifth, the major generalizations of science previously discussed are general *content* objectives. Note this important point, however: Generalizations are here considered as important for objectives only as they arise definitely out of problems, situations, needs, and interests of young persons and society. This is the same check on educational validity as that proposed by the Thirty-first Yearbook Committee.

If generalizations are so considered, it will be clear that they are to be developed within problem or need situations and their elements will appear in situation after situation until the repeated, though partial, experiences will inductively draw the learner to the place where he accepts and understands the generalizations because they apply to many problem situations in which he has been involved and will aid him in probing future problems that he will encounter.

For example, the knowledge that communicable diseases are caused by microorganisms may be considered as a generalization and a general content objective. It is important and probably will be learned (other than in a verbalistic sense) only as young people see that the problems of keeping healthy and avoiding disease demand some understanding of how diseases are caused. General content objectives are of use, not to be taught for directly, but to delimit more specifically an area of human need (health in this case) in which specific and operational objectives can be determined.

Sixth, specific content objectives can be deduced logically from general content objectives. If, for example, the general content objectives were to develop sufficient understanding of human anatomy and physiology to maintain health, the following specific content objectives might be considered. (They are by no means represented as an inclusive list.)

1. The body lines of defense against disease
   a. Nature and construction of skin and mucous membranes as protective tissues
   b. Blood and phagocytes in terms of general immunity
   c. Antibodies in terms of specific immunity and the theory of antigen fixation
2. The body defenses against injury
   a. Skin and mucous membranes
   b. Bony framework and cartilaginous system in terms of movement arms, relation to musculature, and tendencies to strain and tearing
   c. Reflex action and the autonomic system
   d. Parts of the body particularly susceptible to injury in terms of statistical data obtained from morbidity tables
3. Organs and tissues particularly susceptible to disease
   a. Lungs and respiratory system in terms of respiratory infections
   b. Skin and mucous membranes in terms of infection
   c. Heart and circulatory system in terms of rheumatic fever and diseases of the renovascular system
   d. Eyes and ears in terms of common infections and degenerative conditions
   e. Sinuses and fenestration of the bony cavities in terms of the communication of the mucous membranes and tendencies toward the spread of respiratory infections

f. Alimentary canal in terms of infections, irritations, and malignancies
g. Functional interdependence of the human body
h. Changes in the human body accompanying physiological aging; the nature of sclerosis and the process of aging
i. Hypersensitivity
j. Degenerative changes and malignancies

The items in this list are stated as topics. It should be understood that they should be thought of as operational objectives. For example, "degenerative changes and malignancies" might be thought of as "to develop sufficient understanding of the nature of degenerative processes and malignancy that the student will recognize the conditions that are the result of the process of normal physiological aging, clearly recognize the symptoms of cancer, and understand the importance of securing competent medical advice and attention should such symptoms occur." In short, each specified content objective should be functionally oriented to attitudes, skills, and behaviors that are important in the life of the learner.

It should be reiterated that functional learnings cannot be achieved without real understandings of the basic principles of science, which provide the generalized insights upon which sound attitudes, skills, and behaviors depend. The principles of science, and the important facts as well, are involved in these functionally oriented objectives. They are there, but they are properly subsumed under objectives that are directed toward human values.

It is possible, of course, to develop a detailed listing of the scientific principles and generalizations which are directly relevant to any listing of functional objectives. For detailed lists, the reader is referred to reports in which others have presented the principles which they consider important for science instruction in general education.[2]

Bergman made a careful analysis of principles from the field of entomology that he felt were of considerable significance. He listed 52 such principles and associated them with another list of principles of biology developed by Martin. Martin's studies resulted in a list of principles which he names in order of their decreasing value for general-education purposes. Martin's study, as reported in *Science Education,* lists 100 major biological principles. His complete list of 300 principles is available by application to the U.S. Office of Education, Washington,

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[2] There are many such studies. The following are representative: George J. Bergman, "A Determination of the Principles of Entomology of Significance in General Education," *Science Education,* 31:23–32 (February), 1947; *idem,* Part II, *Science Education,* 31:144–157 (April), 1947; W. Edgar Martin, "A Determination of the Principles of the Biological Sciences of Importance for General Education," *Science Education,* 29:100–105 (March), 1945; *idem, The Major Principles of the Biological Sciences of Importance for General Education* (U.S. Office of Education, Circular No. 308; Washington: Government Printing Office, 1948), p. 30.

D.C. (free). This list is arranged under twelve topical headings, such as genetics, heredity, and conservation.

Martin has also presented two articles which consider the various research studies relating to the use of principles as objectives of science instruction. The first of these studies[3] discloses trends in the organization of content and experiences. The second[4] utilizes the frequency of occurrence of biological phenomena and principles in magazines and newspapers as a basis for the determination of important topics. Martin concluded that human biology, health and disease, animal biology, foods and nutrition, and plant biology are of major importance as broad areas for inclusion in general education programs.

Similar studies and reports have been made for the physical sciences. Wise[5] presented 270 principles of physical sciences arranged under major topics in physics, chemistry, and geology. This listing and the relative importance of the principles were determined by a study which Wise reported in another article.[6]

The difficulty of using such lists is that a direct approach to the teaching of the principles as listed risks the danger of resulting in verbalistic teaching and verbalistic learning. Unless the principles are developed inductively within the framework of an attack on significant problems, the learner is likely to learn them as verbal expressions only. He will probably be no better able to use them than if he had never been given instruction in science.

It is of interest that considerable work toward making science instruction functional through developing objectives based on human needs and problems has gone on at the college level. The reader will profit from studying some of the reports of this work. Washton[7] suggests procedures for selecting major principles of science and applying them to objectives of general education. He discusses the relation of science to atomic energy, health, changes in society, communication, and so forth. Rush[8] developed objectives for instruction in physical science and applied the criteria of student needs and potential resources, such as intellectual

[3] W. Edgar Martin, "A Chronological Survey of Research Studies on Principles as Objectives of Instruction in Science," *Science Research*, 29:45–52 (February), 1945.

[4] W. Edgar Martin, "A Chronological Survey of Published Research Studies Relating to Biological Materials in Newspapers and Magazines," *School Science and Mathematics*, 45:543–550 (June), 1945.

[5] Harold E. Wise, *The Major Principles of Physics, Chemistry, and Geology of Importance for General Education* (Washington: U.S. Office of Education, 1948), p. 18.

[6] Harold E. Wise, "Determination of the Relative Importance of Principles of Physical Science for General Education," *Science Education*, 25:371–379 (December), 1941; 26:8–12 (January), 1942; 27:67–76 (September-October), 1943.

[7] Nathan S. Washton, "What Science Course for General Education?" *Association of American Colleges Bulletin*, 35:509–518 (December), 1949.

[8] R. I. Rush, "Determining and Implementing Objectives for a General Course in the Physical Sciences," *Journal of General Education*, 2:138–143 (January), 1948.

prowess and personality traits, that might be developed through a study of the science. Nedelsky[9] presented a method of arriving at and formulating behavioral objectives for the physical sciences, which included knowledge, ability to utilize the methods of science, and scientific attitudes and habits. He developed criteria for achievable objectives. These included communicability, teachability, testability, and comprehensiveness. Nedelsky insisted that teaching should be based specifically and consciously on such specific and clearly seen objectives. Hall[10] presented an analysis of six possible organizations of biology courses in which he included a laboratory exercise in which students are led to discover the process of mitosis for themselves. Hall believes, as does the present author, that the students should be led to make generalizations for themselves rather than be given ready-made generalizations to commit to memory.

Stephens College, a women's college in Missouri, has had a long history of experimental work designed to make science instruction more functional. Van Deventer[11] described the program there and some of the bases on which it was developed. Although it is a college program, the emphasis on meeting the individual needs of the students makes this report worth examining. Van Deventer[12] also described the methods of operating this biology course, which have resulted from eight years of experimentation with individualized techniques. Todd[13] has presented an analysis of the criteria employed at Colgate for the development of a course in biology which is focused on a problem approach. Another report concerning general education in science at Colgate University was presented by French.[14] A course entitled "Problems of Natural Science" is based on ten problems in physical science. The second semester, which was separately reported by Todd, is based on seven problems in physical science. The basic philosophy behind both these courses is that the nonscientist should have ample opportunity to learn the social significance of science and the philosophy of science. But French also points out that the courses should be of even greater value to the scientist-to-be, because the formal program by which the scientist is trained contributes little or nothing to the philosophy of science or its social implications.

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[9] Leo Nedelsky, "Formulation of Objectives of Teaching in the Physical Sciences," *American Journal of Physics,* 17:345–354 (September), 1949.

[10] Thomas S. Hall, "Implications of General Education for the Teaching of Biology," *Journal of General Education,* 2:107–116 (January), 1948.

[11] W. C. Van Deventer, "Organization of a Basic Science Course," *Science Education,* 30:201–206 (October), 1946.

[12] W. C. Van Deventer, "Individualized Instruction in a Basic Science Course," *Science Education,* 30:269–273 (December), 1946.

[13] Robert E. Todd, "Biology in a Program of General Education," *Journal of Higher Education,* 20:71–76, 113 (February), 1949.

[14] Sidney J. French, "Science in General Education," *Journal of General Education,* 1:200–205 (April), 1947.

David Delo, executive director of the American Geological Institute,[15] has written that a firmer basis for sound living and good citizenship would accrue if traditionalism was discarded and science instruction for general education was based upon the attack on such national problems as good land use and the problems of water and mineral-resource use and development.

One of the most interesting college attempts at experimental departures from tradition and the field-covering or survey approaches to science instruction is that underway at Antioch College. A two-year sequence of life science constitutes a course in which man is considered in relation to his environment, both natural and social. The course integrates anthropology, sociology, biology, and psychology, and represents, at the college level, a core program. As in the better high school core programs, the college students at Antioch have the services of experts in all the related fields as they tackle problems in their two-year course.[16]

Finally, the reader will be interested in two reports, published in 1950 and 1951, respectively, which present the deliberations and views of scientists and educators concerning science in general education. The first[17] is a report of a conference on general education held at Florida State University. The article "Science in General Education at Mid-Century" by Konrad B. Krauskopf, Professor of Geology, Stanford University, is particularly of interest. The other report[18] is of a conference held at the University of Minnesota. Both reports represent the considered views of experienced college teachers and offer proposals for the future of general education in sciences, as well as in other fields.

THE DEVELOPMENT OF RESOURCE UNITS

The six steps, discussed earlier in this chapter, in the ordering of curriculum work from areas of need through pervasive, general content and specific content objectives constitute an effective method of gearing the actual teaching to the needs and interests of young people and society. The method is not just a theoretical, armchair construct. It actually works and has been employed by thousands of teachers.

Working backward, it will be seen that activities are developed and provided for in the teaching process which aid young people in the attainment of specific objectives (skills, knowledge, attitudes) which lead toward the realization of general content and pervasive objectives which, in turn, may culminate in the successful meeting of felt, predicated, and social needs.

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[15] David M. Delo, "Role of the Earth Sciences in General Education," *Science,* 112:50–60 (July 14), 1950.

[16] Henry Federighi and Clarence Leuba, "The Proper Study of Mankind Is Man: A Two-Year Course on Man and His Relation to the Living World," *Journal of General Education,* 2:193–198 (April), 1948.

[17] Robert D. Miller, *General Education at Mid-Century: A Critical Analysis* (Tallahassee, Fla.: Florida State University, 1950).

[18] H. T. Morse, *General Education in Transition: A Look Ahead* (Minneapolis: University of Minnesota Press, 1951).

Such preplanning does not stereotype teaching. It is not a teaching unit or even a resource unit, but it should precede the construction of either. It is a master plan to avoid the large danger of doing sterile work in science teaching. The work of preparing such a master plan for teaching is tedious, but it is richly rewarding in assuring significant teaching. It is an obvious technique, but its employment more widely by science teachers is long overdue.

The preplanning that has been suggested should be followed up by the preparation of resource units. A resource unit is not a teaching unit, that is, it is not a careful plan of instruction for a specific group of youngsters and a specific course for a particular semester. It is rather another stage in master planning for highly flexible teaching that could appropriately be used with various classes and at different times. A resource unit is what the name implies. It is a wealth of teaching suggestions from which the teacher can select as the need arises.

Typically, a resource unit has the following parts.

1. A broad statement of emphasis and a more or less detailed listing of objectives to be achieved (developed from a procedure similar to the six steps discussed above).
2. A variety of suggestions for launching the unit. These suggestions provide the teacher with a flexible listing of activities from which he can select as the occasion demands. It might include a detailed list of references for the students, films that are useful for overview or which are particularly challenging in presenting the broad field the unit will cover, other audio-visual aids, demonstrations or experiments, field trips that would set the problem in better focus, or the use of experts. The opening activities should generally do two things for the students. They should challenge them so that they develop a strong interest in tackling the problems of the unit, and they should help the teacher appraise the attainments of the students in terms of the objectives of the unit *prior* to the work of the unit itself. Thus, the initial activities might well provide for group work, discussion, paper and pencil tests, and other techniques whereby the teacher can determine what the students know and think in terms of the unit which is to be developed with them.
3. A variety of suggestions for the main activities of the unit. These will include the types of suggestions that were listed for Step 2 in the construction of a resource unit. But the main body of the unit should be concerned with refining and delimiting the problems to be tackled, securing data on those problems, testing the data and conclusions for validity, and generalizing and applying the data and conclusions to other situations. This means, therefore, that this section of the

suggestions the teacher prepares for his own guidance in teaching a functional, problem-approach unit will be extensive and rich in variety, for the teacher cannot determine in advance just where the work of the group will move. He must determine as fully as possible the sources of data that will be needed, the references, organizations, and experts that might be contacted, the audiovisual materials that are available or may be obtained when and if needed, the field studies that might practicably be undertaken, and the demonstrations and experiments that might be rewarding and the equipment necessary to undertake them. The more complete this preplanning and prestudy of possible activities and materials by the teacher, the more will he be able to provide many different kinds of experiences for his students, with assurance of developmental learnings and the achievement of his objectives. If such preplanning is not done, the teacher will find that the work will flounder, and soon he will be back teaching the easy, if sterile, procedure that the textbooks dictate.

4. The final part of a sound resource unit is a variety of suggestions that the teacher preplans to provide for a satisfactory termination of the unit. This part of the unit should provide for summarization, further applications, and deductions of the generalizations secured in the body of the unit, and for testing of the objectives around which the unit was developed. Again, many sorts of techniques can be employed and all should be listed so that the teacher can utilize those that seem most appropriate with a particular class and within a particular situation. These activities can include demonstrations, panel presentations, individual reports, group discussion and analysis, films and other audiovisual aids, guest speakers, written reports, letters to the editors of the local papers, presentation to the community, and other activities useful either for summarization, action, or evaluation.[19]

The following chapters in this section present detailed suggestions for the use of the classroom and laboratory, community resources, and audiovisual aids, and the evaluation of the results of instruction. If these are seen in terms of

[19] For further discussion of resource units and examples, see H. B. Alberty, *How to Make a Resource Unit* (Columbus, Ohio: College of Education, Ohio State University). Mimeographed. See also the Appendix of Progressive Education Association, *Science in General Education* (New York: Appleton-Century-Crofts, Inc., 1938). For an example of published resource units in science, see Anita Laton and Edna Bailey, *Suggestions for Teaching Selected Materials from the Field of Sex Responsiveness* ("Science and Modern Living Series"; New York: Bureau of Publications, Teachers College, Columbia University, 1941).

the concept of functional teaching through the problem or needs approach, and in terms of preplanning for sound instruction as developed in the present chapter, they should lead the reader to a kind of science teaching that is challenging, dynamic, and capable of producing a higher level of intellectual, emotional, and ethical maturity in his students than could ever be achieved from a textbook-dominated, field-covering approach. (See Part IV for illustrations of functional teaching in action.) Functional teaching takes work. The teacher who employs it will find that he is kept busy and that it requires both careful and fast thinking. But he will never be bored. And he will have the satisfaction of knowing that his science is a living, dynamic force in the lives of his students. Once he applies this concept of teaching, the teacher will never go back to the rote instruction of the field-covering approach and the domination of the textbook.

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8

FUNCTIONAL CLASSROOM AND LABORATORY PRACTICE

The formal science classroom of lecture and student recitation and the separate and equally formal laboratory where students perform manipulatory exercises called "experiments" are part of the less desirable residuum of the past in American education. The standard practice remains from a time when it was believed that it was possible to develop the mental sinews by sufficiently rigorous exercise on any formal material, so long as it was difficult enough. This concept of strengthening the hypothesized "faculties" of the mind has long since been exploded as completely fallacious, but the practices it brought into being still exist in many classrooms throughout the nation.

FACULTY PSYCHOLOGY AND THE FORMAL PROGRAM

It is possible to develop the biceps or other muscles of the body by sufficiently long application to the lifting of increasingly heavy weights, such as dumbbells or bar bells. The muscle so developed can then be used to lift equally heavy weights of almost any description. Poise and flexibility in control are another

matter. But any weight, if it is sufficiently heavy to offer sufficient resistance to the muscle cells, will cause them to increase in size and, therefore, to be more capable of lifting any kind of weight.

The now discredited "formal discipline" or "faculty" school of psychology assumed that something similar would occur if the mind was given sufficiently rigorous exercise. Subject matter of almost any nature was considered adequate for the job, although the more esoteric and apart it was from everyday meaning for the student, the more it was thought to contribute to this strengthening of the hypothesized faculties of the mind. Cogitation on any sufficiently difficult problem was considered to discipline the mind in critical analysis and to result in an increased ability, therefore, to analyze critically any sort of problems that might arise later in the student's life. The student who strengthened his analytical faculties on Newtonian physics was, *ipso facto,* more capable of analyzing the issues of a national election or of interpreting electromagnetic phenomena. For the *faculty* of analysis had been strengthened and could, therefore, be applied to any sort of problem.

Laboratory practice was considered to be a particularly admirable device for strengthening the faculties. The formal laboratory manual and the detailed exercises it often required were considered to foster neatness and accuracy in all endeavors of life. The careful manipulation of apparatus and the meticulous observation and recording of details were believed to develop the faculties of observation, critical deduction, and accuracy of work. Laboratory manuals in biology can still be found which emphasize detailed dissection and careful drawings of lower forms of life. In the phylum approach, for example, the earthworm is used as an example of the Annelida. Dissection of the earthworm is accompanied by detailed and stippled or colored drawings of the major organs *in situ.* The memorization of such terms as *supraoesophageal ganglion, suboesophageal ganglion,* and *circumoesophageal ganglia* is considered of self-evident importance—not so much because of any belief that knowledge of such terms was of practical benefit to the student as because it was thought that such work and memorization would develop the mental faculties of memorization, thoroughness, and critical observation.

By the time that this concept of faculty psychology and the belief in specific mental faculties had been discredited, much of the classroom and laboratory practices of American schools had been standardized in a formal mold. These practices still persist, although their reason for existence has been demonstrated to be completely fallacious. There is a place for formalized laboratory work and class presentation, which will be considered later in this chapter, but the retention of such practices as the chief or only pattern of science instruction is mainly due to intertia, coupled with the fact that many teachers are confused about how to modify their instruction so as to realize the values inherent in the problem or functional approach.

MODERN PSYCHOLOGY AND THE INTEGRATED PROGRAM

Earlier chapters have considered the theory of modern instruction, which is built upon our present knowledge of young people and the learning process (see particularly Chapter 5). But to translate the theory into practice is exceedingly difficult for teachers whose own training has been under the domination of formal, field-covering practices. The first step in the development of sound programs of instruction is to preplan, clarify objectives, and develop resource units, as described in the preceding chapter. This will provide the needed clarity of purposes and necessary procedures for the teacher to move away from the formal textbook- and manual-dominated program.

Science teachers who have learned how to teach by the problem approach are more concerned with the attainment of reflective and critical thinking than were their predecessors. They are concerned with developing critical observation, thoroughness, and accuracy fully as much as were the teachers of the formal discipline school of psychology. But they recognize that these traits are not developed in the same way as the body musculature. They know that there must be practice and experience in a wide variety of activities if these aspects of intellectual discipline are to function in the wide variety of situations which the students will face in their daily life outside the cloister of the classroom. They teach with a critical awareness of what is now known about the psychology of learning, the transfer of training, and the thinking process.

The goal of modern science instruction is not so much the development of discrete factual knowledge (important as functional knowledge may be) as it is the development of generalized insights, useful control of the major principles of science, power of self-learning, and increasingly reflective and critical thinking in situations which present real problems to the students. This goal is not particularly new, of course. It has been presented and analyzed in report after report on general education. An earlier statement of the goal was made by the Committee on the Function of Science in General Education of the Progressive Education Association. The following brief quotation from this report illustrates the basic philosophy around which the entire volume was organized.[1]

> The value of problem-solving through laboratory work in the school does not lie in the factual knowledge that may result from it but in the attitudes and habits of reflective thinking it encourages and in the understanding it gives of how the knowledge of science gained by the student from description was attained in the first place.

Although the committee undoubtedly overstated its case in denying the power-

[1] Progressive Education Association, *Science in General Education,* Report of the Committee on the Function of Science in General Education (New York: Appleton-Century-Crofts, Inc., 1938), p. 317.

ful contributions of the problem-solving approach in the development of factual and durable knowledge, its emphasis on providing experience in critical thinking and problem solving is one that has steadily grown as experience and research have demonstrated its superiority to conventional practice (see Chapter 4). That the committee was not thinking of academic problems conjured into being to train the "faculties" is clear from the following statement.[2]

> If he [the teacher] denies them [the students] the satisfaction of searching for the solution of a problem by providing them in advance with a solution that they might otherwise have reached for themselves, or if he is unsympathetic toward the mistakes they make in trying to think through problems for themselves, he may destroy their confidence and initiative and make them increasingly dependent upon authority.

Most of the experiments presented in present-day science manuals and textbooks or carried out in science laboratories preclude the possibility of much reflective thinking on the part of the student. Too often the student's only job is to follow directions in an effort to achieve accuracy in results he already knows. Too often the subject of the experiment has little or no real interest or motivating value for the student, who, as a consequence, follows the directions without question or real understanding. Under these circumstances it can hardly be expected that the student will develop resourcefulness and facility in employing the scientific method.

How can the science teacher vitalize his classroom and laboratory work so that critical thinking and effective and durable learning will result? It must be repeated that the first step is to preplan the objectives of instruction and to develop a master plan based upon these objectives, as was elaborated in the preceding chapter. Without such preplanning, the teacher has little but the textbook and the laboratory manual to guide him. He has no objectives. He has only a general and usually quite hazy notion that his instruction will develop critical thinking on the part of the students and some retention of important science data and principles. But with a careful job of preplanning in which these hazy goals are clarified and specified in terms of pervasive and specific content objectives, he can develop resource units to which classroom and laboratory work can be pegged with assurance of developmental learnings.

Once this job of careful preplanning and developing resource units is done, the job of functional teaching becomes relatively simple. The big task is to plan what is to be done and to organize the possible materials and techniques of instruction into a master plan. If the teaching is then done on the basis of this flexible master plan and if it is done through the process of group planning and on the basis of real problems that emerge from such planning, the work will have real, functional values, and the classroom and laboratory will achieve a unity that is impossible under a formal, textbook approach.

[2] *Ibid.*, p. 134.

Schedule Difficulties in Integrating Instruction

In most schools, one of the chief barriers to the development of a sound program of instruction based upon the problem or functional approach is the mechanical or administrative problem of scheduling laboratory periods. The conventional system, of course, is to provide two double periods a week for laboratory work (usually on Tuesday and Thursday) and three single periods for classroom lecturing and recitation. This stiffens the learning process in an academic mold that cannot be defended either theoretically or empirically. Under such a schedule, the students go into the laboratory on the prescribed days, open their manuals, and go through the motions of carrying out "experiments." There is little or no psychological or actual relation between such laboratory work and the recitations or lectures that must fit into equally tight little time compartments on Mondays, Wednesdays, and Fridays. Quite often the laboratory work and the classwork get progressively out of phase. And where there is insufficient laboratory equipment for each student, it is common for some students to be carrying on "experiments" in the laboratory weeks or months after classroom instruction on the subject. Others may be doing laboratory work weeks or even months before the content to which it refers is mentioned in the classroom. Such laboratory work may spread the use of a single piece of apparatus to the entire class and may have some limited value in terms of visual demonstration of scientific phenomena. But the practice cannot be defended, for the visual values can be achieved in higher degree and much more efficiently and economically through teacher demonstration that is synchronized with the subject matter under analysis in the classroom.

Achieving Integration under Various Schedules

The laboratory should be the hub of activity in science instruction just as it is in the work of the professional scientist. It should not be a separate cloister where the students go at set times to manipulate apparatus for predetermined results.

The laboratory should be a place where *thinking* is done—critical thinking, reflective thinking, focused thinking. It should be the kind of place that the scientist's laboratory is—a place where genuine problems are tackled, when, as, and as often as they are encountered in the process of learning science and its relation to the life of mankind. It should be possible for students to enter the laboratory and remain there as long as need be to answer questions, to solve problems, and to observe phenomena.

The double-period, two-day-a-week schedule does not easily permit the fullest use of the laboratory. On the other hand, a single-period schedule does not provide sufficient time for students to carry on significant work. There are several solutions to the problem, each of which is used by teachers in the United States today. Most teachers, of course, have to operate under the double-period, two-day-a-week

laboratory schedule. But this does not mean that the students have to remain glued to their chairs in the classroom on Mondays, Wednesdays, and Fridays, or to their laboratory stools on the other two days of the week. If the class, or a group of the class, is working on problems that require the use of the laboratory, good modern teachers simply make the laboratory available every day of the week. Students set up their equipment and continue to work with it, day after day, until they have secured the answers they need. At times, their work will consist of the study of reference books in the library, classroom, or preferably in the laboratory itself. Or, for extended periods of time, they will simply work at their experiments. There is nothing sacrosanct about using the laboratory only on Tuesday and Thursday. Good teachers use the laboratory, the library, and the classroom in a completely integrated fashion—when and as needed.

Even if the teacher is forced into a schedule wherein there are no double periods, he can still utilize the laboratory and classroom in an integrated fashion. Dynamic, functional, problem-approach instruction requires flexibility and integrated work. The teacher who tries it will find, furthermore, that the laboratory is in considerable use outside of class hours. Under such a program of instruction the students are not going through the motions of repeating "canned" procedures. They are psychologically involved and are working to *learn!* When the problems are real to them they *want* to learn! The teacher will find his students coming in before school, using the laboratory whenever they can during the school day, and staying long hours after school to continue their experiments, discuss their work with each other, study basic reference books—and *learn!* This is real learning. It can be produced and is being produced by good modern teachers all over the country today.

But, if the teacher works under a seven-period week (the conventional one period each day and an additional period on Tuesdays and Thursdays), he can try to change the schedule of the seven periods. A schedule of two consecutive periods a day for three or four days a week is far superior to the conventional schedule. This would allow students to work uninterruptedly for two periods a day for three or four days of the five-day school week. The remaining day or two can be utilized by the students for study-hall or library work. Some schools now employ this schedule. The teacher should give it careful consideration and perhaps recommend its adoption in his school.

Of course, the best schedule for functional science teaching would be two consecutive periods each day of the week. The science teacher should attempt to secure such a schedule for his elective sciences at least. Few administrators, parents, or students will object to such a schedule if it can be demonstrated that the time is being put to good use and that sound learnings are resulting.

Two Examples of the Integrated Classroom Laboratory in Action

Whatever the type of schedule the teacher is able to effect, he should make certain that his instruction integrates the various phases of learning activities into a meaningful and developmental whole. Group planning, lectures, discussion, guest

experts, reference work, demonstrations, audiovisual aids, and the laboratory should be flexibly employed as needed as problems are attacked within the framework of the teacher's preplanned resource units. Following are two examples of how science teachers have integrated their instructional work under the conventional schedule of seven periods a week, with double laboratory periods.

A chemistry class. The first example concerns a chemistry teacher who was convinced of the importance of working on the problems that the class developed as a group. He was further convinced that these problems must be solved by the students through their own study, experimentation, and cogitation. This teacher avoided assigning specific days for the laboratory work. The laboratory was used as needed by the students for work on their problems. Over a period of years, this teacher had accumulated a large number of basic reference books, which were kept on shelves in the laboratory rather than in the somewhat inaccessible library. The fixed chairs of the classroom had been changed to moveable seats and tables that permitted a flexible program of general class instruction, small group discussions, individual study, and reference work, as the need arose. The basic experiments in chemistry which were considered fundamental in providing a visualization of the study were generally demonstrated by the teacher. In addition, several weeks at the beginning of the school year had been used for daily individual laboratory work whereby the students learned basic manipulations, care of materials and equipment, and rules of safety.

In general, however, both the laboratory and classroom were devoted to the integrated study of functional problems. The report of this instruction concerns one unit of work that was developed early in the fall semester out of the interest of several students in the class in water-borne infections and the problem of providing pure water for the community. The town drew its water from deep-shaft wells. Further purification of the water was not necessary because of the filtering action of the sandy soil. But one youngster had developed a bad case of eye infection, apparently from swimming in the community pool.

A trip to the community pumping station and to the swimming pool disclosed the methods used in securing the water (and purifying it at the swimming pool) but did not answer the question of the adequacy of the methods employed. Several members of the class had formerly been biology students and were strongly of the opinion that a danger of water-borne diseases of epidemic proportions might exist. Others, who came from farms nearby, were concerned about the purity of their drinking water and the desirability and possibility of purifying it and testing its purity.

These questioning attitudes, differing opinions, and rising interest in problems of community importance might have quickly died if the teacher had responded with direct expository and arbitrary statements. But he considered that such interests and mind-sets were the bases upon which sound instruction designed for the development of intellectual and social maturity could be built. He realized that such interests, if carefully encouraged and directed, might arouse

social sensitivity and necessitate critical thinking and sound chemistry learnings —and to a far greater extent than would be possible through a perusal of the conventional experiments offered in laboratory manuals.

He therefore nurtured the suggestions that were made and helped the class develop procedural plans by which to attack the problems. Some of the students who had previously taken biology suggested the advisability of testing for *E. coli* through the use of fermentation tubes and of making bacterial counts on agar plates. These students were given the responsibility for this phase of the investigation. Although the instructor assisted at all points of the investigation, the students took the responsibility and carried out most of the investigation. The investigation included contacting medical doctors in the town for help on procedure, writing to the state water laboratory, and purchasing a reference book which was recommended by the state water-laboratory personnel.

The instructor prepared a set of mimeographed outlines of chemical analysis of water for nitrates, nitrites, hydrogen sulphide, organic ash, and sodium chloride. The chemical tests were colorimetric and were based upon the amount of these organic compounds in the various water supplies that were in excess of those found in the presumably pure ground water obtained from the deep-shaft community wells. This provided a precise quantitative check on organic contamination, although, of course, it did not disclose evidence of bacterial contamination.

Both bacteriological and chemical analyses were made not only of the community water supply and swimming pool but of well water from many sources, water from the school swimming pool, from the nearby river, and from various ponds and cisterns near and in the town. The work on this project included field activities, discussion with experts, written communication with experts, a large amount of reference work, and considerable experimentation that lasted over several weeks. The students worked with enthusiasm, persistence, and care. The resolution of the problems they set themselves required careful and critical thinking and sifting of procedures to ensure the use of sound ones. The results they obtained in the laboratory required considerable discussion and checking with authoritative sources before sound inferences, conclusions, and generalizations could be obtained. Each sample of water was analyzed by two groups of students working independently of each other so that the results could be checked. These results were further compared with those obtained by the students analyzing the samples bacteriologically. Close agreement was not secured in every instance. But, in general, the results coincided extremely well. Most important educationally, these students were not passively checking textbook and manual statements of fact known prior to the "experimentation." They were engaged in answering real problems by the best scientific methods they could discover. They were using the laboratory as a scientist uses his laboratory, that is, to answer questions unanswerable in any other manner. And during these weeks of activity there developed an appreciation of analytical and quantitative chemistry, its work, difficulties, and value to society. Finally, such conventional objec-

tives as increased ability in balancing equations, determining valences, and so forth, were achieved to a higher degree than ordinarily obtains as students study chemistry in a rather passive fashion from the daily lessons and assignments of a formal textbook.

A biology class. The second example concerns a biology class and the routing of certain common superstitions. The mind which accepts without question such superstitious and basically magical beliefs as those concerning black cats and bad luck, Friday the thirteenth and ominous occurrences is a mind which does not demand knowledge of causal relations. It is a mind that may be equally credulous of demagoguery, false doctrines, and political "isms" of any sort if these are dramatically and emotionally presented. The direct attack on political credulity and the development of rational, reflective thinking where strong emotions are involved are difficult. One path toward developing critical thinking and dispassionate evaluation of issues and doctrines is through the analysis of cause and effect relations in the simpler and less emotionally freighted area of common superstitions.

How shall the teacher help students to eradicate superstitious beliefs and to develop the ability to check their biases against facts? By assertive methods? Try telling a class that the hoop-snake story is a myth or that the glass snake is really a legless lizard which can whip off its tail but cannot break into a dozen pieces and reassemble its parts at will. It will work for those who have never learned the superstition from a valued adult. But for the youth whose own father has actually "seen" these remarkable phenomena, your exposition will be worse than useless. Your assertive methods may rankle, but will hardly convince the very students whose credulity you are particularly anxious to dispel, for you may be setting yourself up as an arbitrary authority in opposition to that highest of authorities, the child's father. Far more important, your proper function is not to state the "truth" in these matters which are, in themselves, innocuous. Your proper purpose is to aid the student in developing the proclivity and ability to analyze objectively any and all beliefs and prejudgments—particularly those which have emotional aspects or which he has accepted as "of-course" assumptions. We want to develop the ability to evaluate critically all propaganda and beliefs, including our own as teachers or students.

The following report of an integrated program of biology instruction concerns a teacher who held it to be his responsibility to encourage critical-mindedness. He taught in a small midwestern town where the glass-snake story was prevalent. When the inevitable glass-snake story came up in the class discussion, it was defended with vigor by many students. It was also pooh-poohed by other students, and the argument waxed strong and heated. The teacher was put on the spot to settle the argument whether a snake could disassemble and reassemble at will.

The teacher did not succumb to the temptation of taking this easy and educationally futile way out. Rather, he led the students in a discussion which recalled the emphasis throughout the course on structuring problems, securing valid data,

and letting the facts speak for themselves. The class had developed a kind of credo that any controversial or problem issue was best decided on the basis of securing as much authoritative information as possible from as varied sources as possible. The entire work of the class had been problem-centered, and the students had many times before tackled problems which required both reference data and considerable laboratory and field investigation. "Why not," it was suggested, "apply what we have learned about sound process to the problem at hand?"

Many sources of information were suggested. A committee of three students undertook the job of determining what reference books were available in the school and community libraries. Another small group went through the files of "fugitive material" (see Chapter 9), and still other groups interviewed people in the community in an effort to find out whether anyone had actually seen the phenomenon or whether it was just hearsay. Letters were written to the herpetology department of the state university and to a herpetologist at the New York Zoological Society.

The most interesting work, however, was done in the laboratory, which in this school was a part of the classroom itself. The large multiple cage, which had been constructed by students of an earlier class and which had housed white rats and a wide variety of animals used for genetic, diet, dissection, and other work, was soon filled to capacity with many kinds of snakes, which the students brought in. Before long, small groups of students were making careful dissections of these snakes. The zest with which they tackled the work and the care with which they did it would surprise the teacher who is acquainted only with the nature of student enthusiasm developed during routine dissections of preserved specimens. Prescribed outlines for the dissection were not given, although help was given on techniques, and considerable discussion and use of college zoology manuals preceded the actual work. The teacher pointed out that the snake was perhaps the most maligned and misunderstood of animals. And he suggested that the class take the time to examine their specimens with care in order to answer the many other questions which had developed in the class discussion as the analysis of the glass-snake story had enlarged to include other questions and problems about reptiles. Some of the snakes were found to be oviparous while others were found to be viviparous and full of the tiny embryonic young curled up in their yolk cases.

The reference work disclosed that there is an animal known as the "glass snake." It disclosed, further, that the glass snake is not a snake at all but a legless lizard. The students were particularly fascinated by an authoritative account by a reputable herpetologist which indicated that a lizard can snap off its tail and leave this wriggling member in the mouth of its witless pursuer while the lizard races off to safety. It was not long before most of the class had decided that this phenomenon could easily account for the prevalence of the story that the glass snake "came all apart" and later put itself back together again.

The teacher had two preserved specimens of the glass snake in his storage closet. These were brought out at the time the students discovered, from perusal of their reference works, that the glass snake really existed. But many of the students were distinctly surprised to see the specimens, for they had not only disbelieved the stories concerning the glass snake but assumed that the animal itself was nonexistent, reference books to the contrary. Comparison of the lizards with photographs from the books on herpetology showed that the animals were the ones in question.

It occurred to one of the students to secure an X ray of the internal anatomy of the preserved specimens. This was done through the cooperation of a local medical doctor, but only the vertebral column and ribs could be demonstrated. Although the dissection of snakes had shown the students the organic wholeness of the bodies of these animals and the impossibility of segmentation and reassembly of the various tissues, organs, and organ systems, several of the students were still—and properly—of the opinion that the glass snake could be different. One student suggested that the internal organs of the glass snake might be jointed in some way. Without more ado, one of the glass snakes was cut open by one of the students while the rest of the class hovered around and offered suggestions.

The work with reference books, data from experts secured through the mails, and the work in the laboratory finally laid the superstition. As one of the students stated it, the glass snake could not "without black magic" tear itself apart, let alone reassemble the severed members. Even the few members of the class who had earlier reported that a member of their own family had seen the glass snake break apart and reassemble itself had decided that these experiences were probably exaggerated and might have been based upon an experience in which a glass snake whipped off its tail. This conclusion was strengthened by the fact that the group which had interviewed residents of the community had found that the stories tended to break down when detailed facts were called for—usually it had been "somebody else" that had seen the thing happen. And the "somebody else" generally turned out to have heard the story from still another person. Herein lay one of the greatest values of the work. The students had not only learned a lot about reptiles and the value of sticking to the facts, they had also learned a good deal about human beings and their foibles and gullibility. In terms of our present purpose in presenting this factual account, the instructional procedure was an excellent, if simple, example of the use of classroom and laboratory in an integrated program of functional learnings. It might interest the reader to know that this particular teacher consistently taught his classes by a problem approach and tested the factual learnings of his students by the Cooperative Biology Examination (one of the better formal objective and standardized examinations). Consistently, the class average was significantly superior to the national average, although factual learnings were subordinated to the larger objectives of functional understandings and critical thinking.

THE PLACE OF LECTURES IN MODERN INSTRUCTION

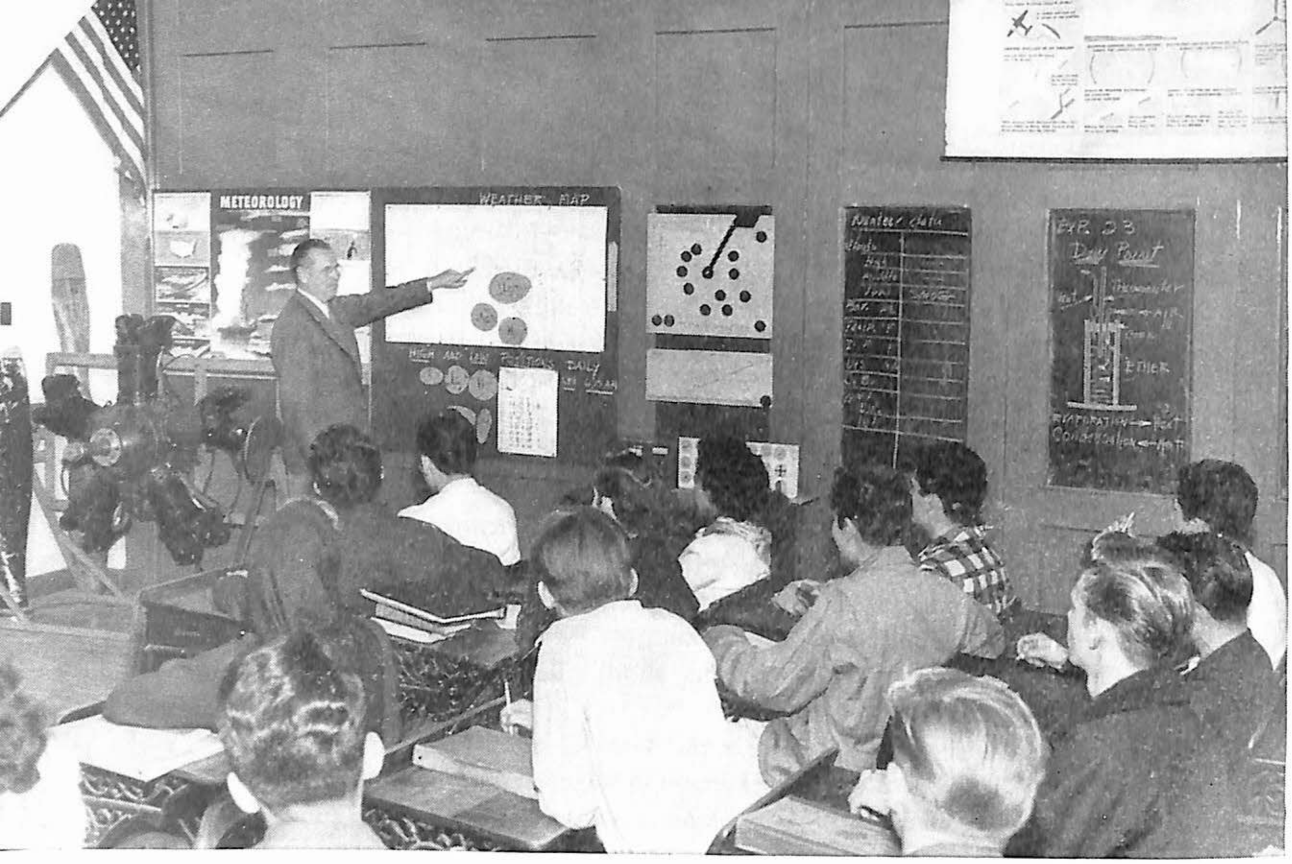
It should be clear to the reader that a functional approach to science instruction by no means displaces the teacher or lessens his importance. His place at the front of the room, hearing recitations of memoritor learnings or lecturing from organized notes, is changed. But his function becomes more crucially important as he challenges his students, guides their development, and assists them as they learn how to study, investigate, experiment, and reflect on the many vital problems such instruction brings to the fore.

Although the teacher is less prominently a dispenser of knowledge in the formal sense of conventional instruction, each of the techniques of conventional teaching have their proper place in the problem approach. The teacher is a mature scholar in the fields he is teaching—or at least he should be. There are many times when his knowledge and training should be utilized for formal instruction of the class as a whole.

There is nothing whatsoever wrong with the lecture method, for example, except that the teacher should understand what the lecture can and cannot do. Often, textbooks, encyclopedias, and other reference works will seem ambiguous to the student. Sometimes their own best efforts will not provide students with the information they seek. At these times—when the students recognize their need for direct help from the teacher—a well-presented lecture or series of informal talks can be all-important.

But the teacher should recognize that a lecture, however informal, dynamic, and clear, is still a process in which the lecturer does the thinking and the students do the absorbing. The lecture should be broken up far more than it usually is to allow the students a chance to reflect on what has been presented, to ask for clarification of points that are obscure, to discuss the meaning and applications of the information, and to offer their own interpretations or opposing viewpoints. While the teacher is lecturing, the students are forced to follow the pattern of the teacher's thinking and are consequently prohibited from doing much thinking of their own. When a student reads from a book, he will, if he has been assisted to see the importance of the process, put the book aside quite frequently and consider the meaning, importance, and applications of what he has read. He will think it through, consider how it fits into what he already has learned, and raise critical questions for himself that need to be answered for clarification or assurance of validity. This is difficult to do while the teacher is lecturing, for the teacher's voice compels the student to follow the thought patterns of the teacher. The student has little opportunity to allow his mind to reflect on what has just been said, for the teacher is proceeding with other words or perhaps another train of thought.

Sound use of the lecture process, therefore, requires that the teacher talk informally, liberally illustrate his chief points by analogies, allusions, and visual

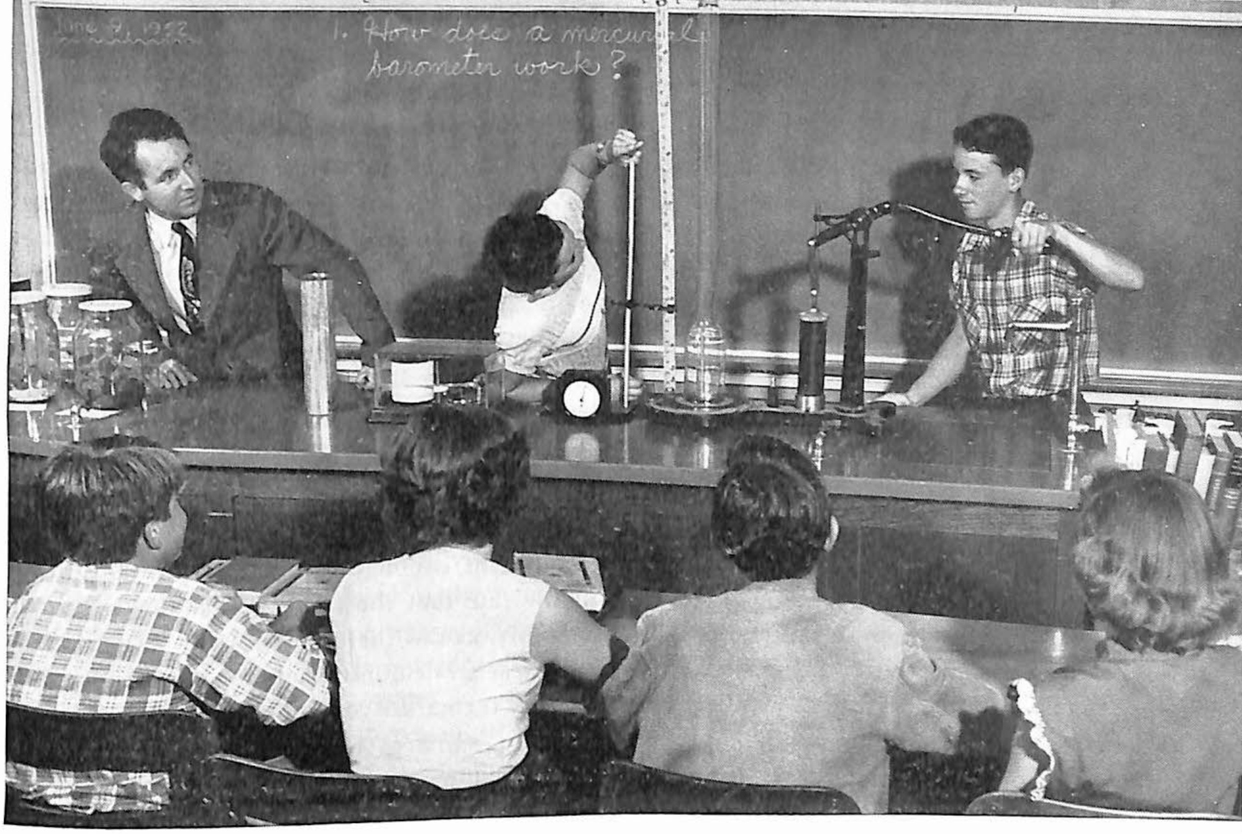


Lecturing is a highly efficient means of imparting information or of clarifying data secured by students through other means. But sound use of the lecture process requires liberal illustration of chief points by analogies, allusions, and visual aids. (Courtesy of Los Angeles Public Schools)

aids, and permit and encourage interruption by the students. Sound use of the lecture process requires that the teacher recognize it as a highly efficient means to impart information or to clarify data secured by the students by other means. But sound use of the lecture method requires, also, that the teacher recognize that it is useful as a means of imparting information but that it restricts the opportunity for students to engage in creative, critical, or reflective thinking while the lecture is proceeding. The teacher who is interested in having his students develop the power of independent thinking will therefore use the lecture method sparingly and see that his lectures are followed up by analysis on the part of the students in class or small-group discussion or in written individual analyses and critiques. The lecture is vastly important to efficient instruction. But it must be kept in its proper place and supported by other classroom techniques.

THE PLACE OF DEMONSTRATIONS IN FUNCTIONAL TEACHING

Good science instruction requires individual laboratory work on the part of the students, for the best science instruction is primarily concerned with the devel-



Teacher demonstrations can, for many purposes, serve a class more adequately than student demonstrations. But where student investigation culminates in information that can be demonstrated effectively for the benefit of classmates its use should be encouraged. More rather than less work for the teacher if they are to be effective, student demonstrations require "dry-runs" under the teacher's supervision prior to presentation before the class. (Courtesy of Los Angeles Public Schools)

opment of critical thinking, independent powers of analysis, and the various attitudes, skills, and abilities that were enumerated in the previous chapter as aspects of critical problem solving. These simply cannot be developed if the student is consistently in the passive position of hearing, reading, and observing the activities and thinking of others. One learns by doing; one learns to solve real problems and to do critical thinking by experience. But there is a place—and usually it is a neglected place—for teacher demonstrations. Verbal descriptions of scientific phenomena and statements of scientific principles need to be supported by realistic experiences if the learner is to appreciate them fully. Students vary in their abilities to learn from words, which are abstractions of reality. All should be helped to increase their powers of critical listening and reading. The teacher can assist students by providing considerable opportunities for the learners to observe the realities behind the words. And for some students, the visual approach is almost a necessity if they are to gain much from science instruction.

The demonstration method has certain advantages over the individual laboratory method in this respect. If the purpose is to provide a clean-cut demonstration

of a principle or phenomenon, the teacher can ordinarily achieve better results than can the student. He has a mature understanding of the principle or phenomenon, whereas the student is at the learning stage where there are many hazy aspects. The teacher is experienced in handling the equipment and in interpreting and explaining it to others, whereas the student tends to be inept and confused about the best means of clarifying for others points of difficulty or ambiguity. It is for these reasons that every science class should have the opportunity of observing many clean-cut, clear demonstrations by the teacher.

A number of studies have been undertaken to determine the relative effectiveness of teacher demonstrations and individual experimentation by the students. These studies appear to present conflicting results. However, careful examination of these studies will indicate that the conditions under which the courses were taught varied considerably, as did the objectives of the teacher. In general, it may be stated that the teacher-demonstration method tends to be superior when the objective is to clarify the nature of a phenomenon or principle. The individual laboratory experiment tends to be superior when the larger objectives of developing critical thinking obtain, and when the laboratory experiments are problem-centered rather than cookbook procedures. Cunningham[3] analyzed thirty-seven studies dealing with the question of the superiority of the demonstration or the laboratory method. His summary and interpretation of the data are worth the reader's attention.

THE PLACE OF DISCUSSION GROUPS, PANELS, AND STUDENT REPORTS

The functional approach to the teaching of science does away with the process whereby the teacher calls on a student from the front of the room, hears him recite, and says, "Fine, John," or, "That is not correct, John; maybe Mary can help us out on this." Such formal, textbookish instruction is neither sound from the point of view of modern objectives and goals or even efficient in developing memoritor factual learnings. A few students are usually ready to respond to the teacher's questions and can recite with apparent knowledge of what they are talking about. But these same students may be found to have but the most superficial and textbookish knowledge of what they are discussing. And the majority of the students flounder badly, strive valiantly to put their hazy thoughts in sufficient order to respond to the teacher's questions, and breathe a sigh of relief when the questions are directed to others in the class. This kind of classroom activity is fear-ridden, causes acute embarrassment to some youngsters, and develops in others a desperate attitude of getting by. It creates a strong distaste

[3] Harry Allen Cunningham, "Lecture Demonstration versus Individual Laboratory Method in Science Teaching—A Summary," *Science Education*, 30:70–82 (March), 1946.

for science in many of the students, and a feeling in others that "I just can't understand science—anyway I hate the stuff."

Modern teachers allow the classroom work to grow out of common purposes, group decisions, and the growing individual interests of the students. Modern classrooms are not pathologically fear-ridden and competitive. They are pleasant rooms. Students are at ease. They are hard at work and there is no foolishness. But they are working at tasks they have helped set for themselves. They understand the importance of what they are doing. There is competition, of course, but it is self-set, not determined by the quest to get better grades than others in the class. Essentially, modern classrooms are cooperative rather than competitive. Each student is expected to contribute his best, and the students, as a group, generally see to it that individual students do not let the group down. But each student finds his level in the reference books he can use, the contributions he can make to the planning of the group, the laboratory work he can perform, and so forth. He is not censured because he does not have the same native endowments or background as others in the class. But he is expected to carry his share of the class responsibilities. And the fakers are soon discovered and called to account in a really democratic classroom situation, for the group sets its own standards and rules of conduct—sometimes explicitly, more often implicitly. These standards and rules are usually considerably higher and more rigorously enforced than in any teacher-dominated class for, where a substantial number of a class group identify themselves with the instructional program, understand the importance of the experiences they are having, and help create the procedures under which they learn, they tend to be quite intolerant of interference or the shucking of responsibility by individual members. The teacher has only to observe an out-of-school group of young persons working or playing at self-determined jobs or activities to see this for himself. And the laggards soon catch up within such a psychological environment. They may oppose the teacher's arbitrary will in an autocratic classroom, and often do, because they are proving themselves in front of their colleagues, but they cannot tolerate the condemnation of their peers. Perhaps the basic motivation of any individual is the search for approval and acceptance by valued peer groups—the feeling of belonging. Man cannot stand to be an outsider, to be different and excluded. If given half a chance (and the teacher must see to it that the chance is offered and offered repeatedly if need be), each student in his class will gravitate toward the work of the class group. The centripetal force of group purposing and demand is irresistible. For these reasons, and because of the desirability of placing the learner under the necessity of doing his own thinking, planning, studying, and investigation, modern teachers emphasize techniques that place the student in a positive role in the learning situation.

Functions of Group Discussion

Discussion groups can easily deteriorate into aimless wandering. Or they can develop cogent analysis in which the contributions of the individual members

move the thinking of the entire group toward established instructional goals. Which they become depends upon the teacher's understanding of the nature of group discussion, certain psychological factors that always operate, and his skill in working in a group situation.

Considerable time is often wasted in the employment of group discussion for purposes it cannot achieve. Discussion can never create scientific fact, although it may serve to clarify it or assist in the determination of best ways to locate fact. Group analysis—committee work—is often improperly used to answer questions better answered by individual library work or other forms of investigation. Group discussion should serve to focus attention on the problems to be answered and on interpretations after facts have been made available; it should never be used to supply data. This would appear to be obvious, but it is often overlooked in practice.

Group discussion can be useful in twelve steps in a functional or problem classroom setting.

1. In locating, specifying, and delimiting problems that can be pursued with profit
2. In determining the status of individual and group backgrounds of strengths and weaknesses in the knowledge and skills pertinent to attacking the problem
3. In motivating individuals and developing a group purpose in which individual responsibility will be set and maintained by the group pressure on the individual
4. In analyzing and clarifying procedural steps that are required to answer the major problem and the related subproblems
5. In setting individual and subgroup responsibilities for various phases of the necessary investigation of the problems
6. In summarizing data and reviewing progress at various stages of the work
7. In locating and clarifying areas of vagueness in either knowledge or skills of procedure (although teacher presentation is often a more efficient and superior means of achieving this)
8. In assessing the validity and pertinence of data to the problems at hand (The critical demands of the group for proof and documentation of data presented by individuals or subgroups make this one of the most profitable phases of group discussion.)
9. In developing conclusions that are consonant with the determined facts
10. In developing sound inferences and tentative generalizations that are supported by the facts and conclusions
11. In determining possible and desirable forms of action or behavior that are based on the facts, the conclusions, and the generalized insights developed

12. In evaluating individual student growth in the major objectives of the unit and the course and in diagnosing student difficulties and weaknesses in the instructional procedure

Techniques of Group Discussion

A group is not just a collection of individuals. It does not come ready-made and capable of effective work. It must be created. A group has achieved certain common goals which make it a group, and it is composed of individuals with a mutual sense of belonging, purposing, and responsibility. The twelve steps are useful not only in various phases of problem solving but in creating a group out of a collection of individuals who have different interests, goals, and backgrounds. This creative function is the most important as well as the most difficult aspect of group work, for each individual in a group plays a role that is determined by how he conceives himself and his relations to others.

Each individual has his own longings, fears, and subconscious drives. If the teacher will observe a group in action and will critically analyze what he sees, he will learn much about the nature of a group and the psychological factors that prevent a collection of individuals from becoming a real group. He will find that certain individuals play the role of leaders with ease. They appear to be active-minded, offer suggestions readily, criticize other viewpoints, and in general appear to be contributing a great deal to the work of the group. But the teacher's analysis may disclose some unfavorable aspects to this. He may find that the leader quickly dominates the discussion, and he may come to suspect that the student behaves as he does almost compulsively, that he uses other students to prove his own superiority. The teacher will find other roles being played. There will be the clowns who, apparently afraid to face competition in straightforward analysis, gain their satisfactions of being noticed and accepted by various detour behaviors designed to amuse the class. There will be students who look for opportunities to show up others in the class. As a matter of fact, the teacher will observe that most or all of his students will, from time to time, attack another's views quite obviously to discredit the individual behind the viewpoint rather than to push along the discussion and analysis. (And, if he will examine his own behaviors and their basis, he will find that he, too, often plays the role of detractor, not to help in the analysis, but to "put others in their place" and to enhance his own ego.) There will be students who contribute little or nothing. They have retired into their mental shells to avoid hurt to their egos. There will be various degrees of petulance, aggressiveness, retirement from participation, and eagerness to curry favor or to show off. Such a collection of individuals is not a group. It is the teacher's job to work with them skillfully so that a group emerges from them.

The job is by no means easy. It is never accomplished with complete success. The teacher can never bat 1,000 in any of his teaching procedures. But he can achieve a great deal. To do the job well the teacher should have the following

attributes: genuine interest in the educational growth of his students; the ability to relax and hold his own fears, hurts, and ego involvements in check; and the ability to put his students at ease. A tense, competitive, teacher-dominated situation is not one in which efficient and smoothly working groups emerge. But if the students know that their teacher is really on their side—that he genuinely likes to work with them rather than against them—the major psychological hurdle has been jumped.

The technique of building a smoothly functioning group rests, in part, on helping the students to see the nature of a real group and to recognize the various subconscious roles we all play at times. The teacher can profitably explore the methods used by a typical collection of individuals ostensibly at work on a common problem. He can show the students how such a collection of people usually are sparring at one another, how some try to dominate the discussion, how others retire rather than take the chance of being psychologically hurt, and how some cut up to gain approval and to avoid hurt. He can help them to see how these crosscurrents of psychological purpose tend to destroy the work of the group and stand in the way of group purposing and efficiency. He can do this by sympathetic and good-humored analysis. And he can then engage his students in "role playing." This is a technique whereby each student, or, preferably, a small group of students, enacts various roles for the benefit of the entire class. One student acts out the role of the discussion hog. He has to be at the center of attention all the time and has difficulty letting others enter into the discussion. It becomes quite clear that this student is really not interested in the group or its problem; he is interested in proving how smart he is to the others so that his own feeling of inferiority will be momentarily lessened. Another student plays the role of the class clown. He is motivated by the same compulsions as the discussion hog. But he does not dare try the direct approach of dominating the discussion. He hardly listens to what is going on as he looks for opportunities to show off. Still another student acts out the role of the scared individual who listens to all analyses by others, not for the purpose of learning and contributing to the growth of sound ideas, but for the purpose of finding weaknesses and errors so that he can light in and sadistically show up the others—again, so that he himself will momentarily feel a little better about his own comparative stature.

Many such roles can be enacted. If the students are given a chance to discuss their own feelings and reactions to others they will suggest a number of roles that are quite real. And their enactment of them will help greatly in understanding that their own fears and feelings are shared by others, that they all are much more alike than they had ever dreamed. This psychological identification will tend to help the students relax and to lessen the negative aspects of role playing when they get to the task of actual discussion in real group work.

The teacher should enter into this role playing with the students. He should recognize his own psychological tendencies as clearly as possible. Above all—and this is partly a difficulty growing out of the fact that he *is* the teacher and plays

a typical teacher role—he should avoid dominating the discussion. Time after time, he will find that the "discussion" of the group has degenerated into an interchange between himself and one or a few students. More and more, he may find that he has taken over the discussion and is really presenting an informal lecture. There is nothing wrong with informal lecturing—in its proper place. But the teacher should refuse to allow the sound purposes of group discussion to deteriorate, as students take the easy road of responding only to the teacher and the teacher takes the equally easy road of playing the role of the fount of wisdom.

There is a technique that will assist the teacher and his class to understand better how they have worked as a group and to diagnose their weakness as a group. It is to appoint a student discussion leader, a recorder, and an observer. The job of the discussion leader is not to do all the talking. On the contrary, it is to stimulate the discussion of the group and to provide guidance when the discussion tends to wander or deteriorates into dispute. The job of the recorder is to keep a record of the progress of the discussion so that each member of the group may determine what issues have been explored, what progress has been made, and what matters are still open for analysis. The job of the observer is to provide a report on the extent and nature of the contributions made by the group members. He need not use names but he can assign numbers to the members of the group and then make a notation for each person who contributes to the discussion with some indication of how long each individual's contribution took. After the discussion has been under way for some time, the discussion leader can ask the observer to report on how the group has proceeded. It will surprise most members of the class to notice how the discussion tends to settle down to an interchange between a few members. And, usually, the discussion leader will be found to have pre-empted the discussion. He not only leads the discussion, he tends to take it over (particularly if he is the teacher).

But these techniques should never become so dominant that the main purposes of group discussion are forgotten. Even without the techniques, a well-trained and dynamic teacher will find that group discussion contributes greatly to the process of instruction when the problem approach is used. Sparingly and intelligently applied, the techniques should expedite the process by which an effective group is created.

Student Panels and Student Reports

Student reports in a conventional classroom are often worse than useless. Students are assigned topics or volunteer to report in order to raise their grades or to carry out an imposed job only tenuously connected with study of the textbook, which is the main vehicle of instruction. The student goes to the library, looks through a few articles in a desultory fashion, and writes a report that is full of words he does not understand and ideas that he comprehends but vaguely. He stands before the class and drones out his report. While he is doing

so, the other members of the class are thinking about the reports they will have to give, wondering who will be called on next, or arranging their date calendars in their mind.

The point is that no one, including the student who is giving the report, learns much that is profitable from such unrelated jobs as this. The report remains a paper report for the student who presents it. It is so much verbal mishmash to the students who are forced to endure its presentation—and who generally care even less about the content of the report than does the student who is giving it.

Student reports should grow out of the problems set by the group and in which the group is interested. They should represent critical investigation, thinking, and sound presentation by one or more students on jobs that forward the work on the group's problem. The class should have full opportunity to discuss and analyze the report, and it should be quite critical of any weaknesses in the report—whether inadequate validation, vagueness, or sloppiness in presentation. The class should establish certain rules and regulations for its own conduct. If the student or group that reports has not done its job well, the class should decide whether it should be required to do its job again (see Chapter 10 on evaluation, pp. 265–267).

Student reports are a basic part of problem-approach instruction. Typically, the problems that students attack have sufficient subproblems and require sufficient investigation through reference books, field work, and laboratory work that the work must be divided among the class members. It is necessary, therefore, to provide some means whereby the data secured by individuals or subgroups are presented for the consideration, analysis, and evaluation of the class. If student reports are considered under such a procedure and used for such purposes, they will rarely be the canned plagiaristic reports they so often are under conventional instruction. But the teacher will find it necessary to help his students in preparing their reports just as he will find it necessary to help them at every stage of the group process of problem solving. Students rarely know how to use the library or reference books. This must be taught them. They rarely know how to study. They read for an hour and think they have studied. They must be shown how to break up their reading with analysis of the meaning of what they have read and with mental review of the fundamentals of what they have read. They must be helped to analyze data and to synthesize them for the purpose of preparing intelligible reports. They must be helped to present their data and their ideas with cogency and effectiveness. They must even be helped to listen with intelligence and to take notes that are useful. These, too, are parts of the job of the science teacher who wants his instruction to help his students toward intellectual maturity and social effectiveness.

Panel discussions are often preferable to individual student reports. Where small groups have investigated a problem or a phase of the problem, they will act as checks on each other and will help to clarify the data for the larger class

group if they present the data as a panel, for this provides for the play of mind upon mind, for analysis and discussion by informed individuals of materials that would otherwise be presented in an expository fashion. The science teacher should utilize panel presentations particularly where analysis, as well as data, is desirable. The entire class should enter into the discussion and critically analyze and evaluate the panel discussion. Students will improve in effectiveness of thinking and communication if group techniques are properly employed and if steady improvement is insisted upon. If students are placed in the position where they must *use* the facts and principles of science, at least in verbal analysis, presentation, and discussion, there is much less danger that these learnings will be verbalistic or remain inert until such time as formal examinations are past and there is no reason for even the verbalisms to be retained.

ORDERING AND MAINTAINING EQUIPMENT AND SUPPLIES

In terms of material facilities science rooms can be divided into three categories which have nothing to do with the amount of equipment and supplies they contain.

1. Junk piles of inaccessible, corroded, broken-down materials piled on top of each other without logic and without usefulness
2. Overly neat, carefully assorted materials which are obviously rarely used for demonstrations by the teacher and never touched by the students who should be learning from them
3. Well-assorted, catalogued, and stored equipment that is used, available to qualified students, and kept in good repair

We want to talk about techniques of establishing and maintaining the third category. The beginning science teacher often inherits the junk-pile type of science room. His background of training has given him little help in ordering, using, and maintaining supplies. If he has a budget for the purchase of supplies and equipment, he too often merely adds to the junk pile. If his budget is inadequate, he often orders expensive equipment and supplies with little educational merit and overlooks the necessary materials for functional instruction.

It is pointless to try to be specific about appropriate budgets and supplies; too much depends on the money actually available, the equipment already on hand, and the nature of the instruction the science teacher plans. The only sensible way to work out specific lists of needed supplies is to determine objectives precisely and to develop resource units which specify the experiments, demonstrations, and activities which will be required.

If the teacher follows the textbook closely, the problem is much simpler. The laboratory manuals usually indicate the supplies and equipment required for each student or for a class of thirty. Furthermore, the scientific supply houses

Equipment is too often kept locked up and inaccessible to students or allowed to deteriorate into piles of junk. Equipment should be accessible, kept in good repair, and *used* as an integral part of learning activities. This requires cataloguing, proper storing, and considerable discipline of the student group. It requires time, too, but effective science instruction is impossible without efficiency in maintenance of equipment. (Courtesy of College of Education, University of Illinois)

have worked out complete lists of equipment and supplies to follow each of the major textbooks and manuals that are in popular use. The reader should write to these supply houses for such lists even if he plans a functional ordering of his instruction, for he will get considerable help from them. Because these lists are easily available and kept reasonably up-to-date, there is no need to provide such a list in this volume.

But certain procedures will help the teacher develop sound criteria for the ordering and record keeping necessary to avoid the junk-yard or museum-case types of classroom and will help him to make the best use of whatever budget he may have.

First, it is useful to make a long-range list of desirable acquisitions and to divide this from a list of needed annual supplies. The long-range list should specify basic equipment in order of need. The list of annual supplies should include the materials necessary to replace used supplies and broken materials, repair equipment already in stock, and should include new acquisitions selected from the long-range list.

Second, the teacher should carefully take stock of what materials and equipment he has on hand, catalogue them, arrange them in some functional fashion, and determine what is really junk and what is usable or can be salvaged. In general, it is cheaper to have materials repaired than it is to replace them. The

major supply houses have excellent repair departments and will estimate the cost of repairs if the damaged equipment is sent to them for the purpose. Quite often, the teacher will find minor defects in equipment that is covered with dust. If he is at all skillful in working with his hands, he can repair much of this and secure student assistance in the work. He need not worry whether this is exploitation. If he places no pressure on his students and offers no grade awards, a few students, who have strong interests in science, will welcome the chance to assist in the repairs. And it is excellent training for them.

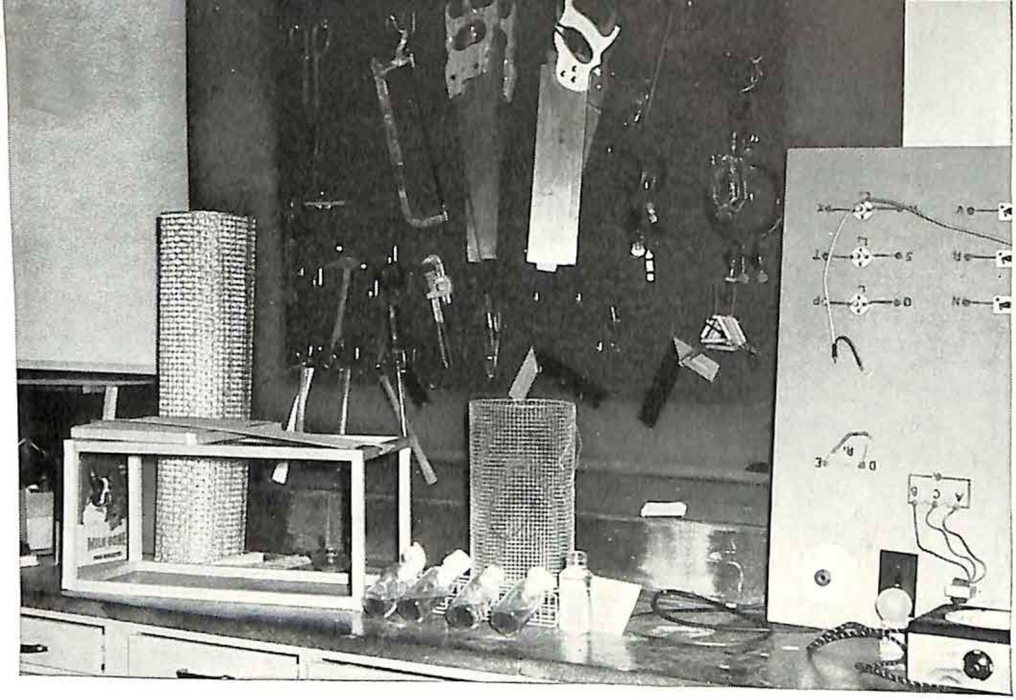
Third, the teacher should place on 3-by-5-inch cards a brief but accurate record of each piece of equipment or item of supply and he should keep these cards up-to-date. There should be a separate card for each piece of equipment, item of supply, chemical, or tool. These cards should record the date of purchase, the condition of the equipment or the amount of material still unconsumed at the end of each year or major teaching unit, and where the equipment or material is stored. The work of maintaining an adequate card index is quite time-consuming. The science teacher should have the services of a paid stock-room assistant. He should work toward this end with his administrators. But it is imperative that adequate records be kept whether he takes care of the chore himself or delegates it to others.

Fourth, when equipment is broken or supplies consumed, the fact should be recorded immediately on the appropriate index card, and the card should be removed from the main file and placed in a separate file. This will facilitate the work of maintaining and ordering supplies and equipment.

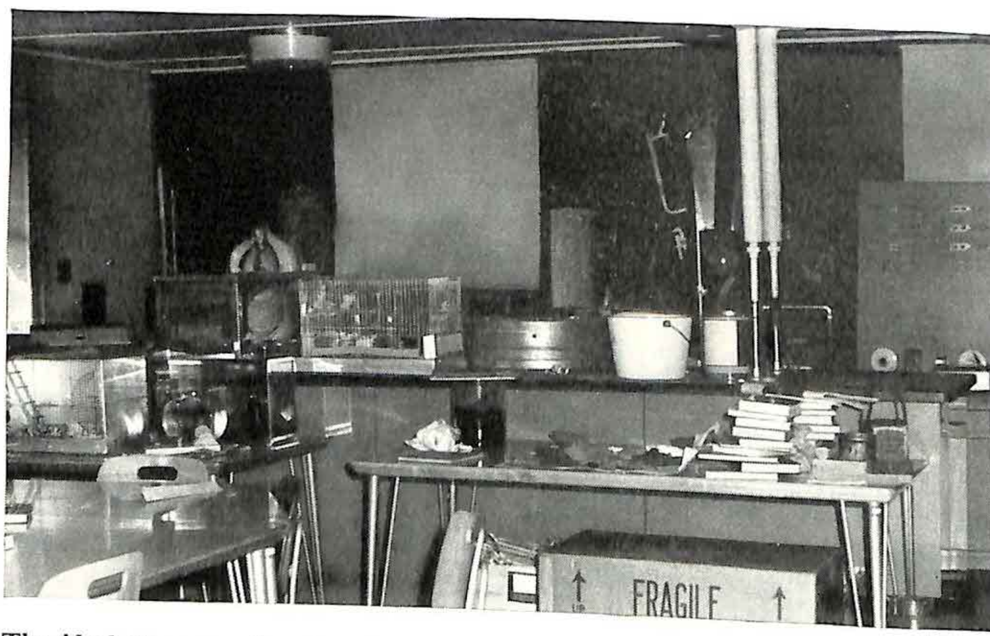
Fifth, the equipment that is broken should not be put back in general storage. It should be examined and, if the needed repairs are slight and can be done by the teacher or his student assistants, it should be placed in a section of the storeroom reserved for repair and maintenance of equipment. If the equipment requires repairs that are beyond the scope of the teacher's ability, it should be immediately packed for shipment and a letter should be prepared specifying the defects in so far as the teacher knows them. The equipment can then be sent to one of the scientific supply houses for an estimate of repair costs, or it can be stored, together with the letter, until the summer or other more propitious time.

Sixth, and very important, the teacher should secure and maintain adequate work space and basic tools for the repair and maintenance of equipment and supplies. "A stitch in time saves nine" is particularly true when applied to science equipment. But the busy teacher will not take the time necessary to provide the needed stitch unless he is equipped to do the job or to have a competent student do it under his supervision. He will throw the equipment back onto the shelf, and soon he has a useless pile of junk instead of equipment.

At the minimum, the workshop or work space should include shelves, two heavy worktables, a vise, a small anvil, a spot welder, and the following hand tools: hammers, including a ball peen hammer, metal shears, wrenches and pliers, drills, bits and braces, screw drivers, wire cutters, glass cutter, chisels, planes,



Handtools, available for use by students and teachers, are conveniently stored on the rack and in the drawers below in this multipurpose science room. They facilitate the construction, repair, and maintenance of equipment and demonstration devices. (Courtesy of College of Education, University of Illinois)



The ideal classroom doesn't exist except as teachers make their rooms into flexible situations where their instructional goals are facilitated. This multipurpose science room approaches the ideal in terms of the teacher's purposes of providing a setting for the problem approach to science teaching. (Courtesy of College of Education, University of Illinois)

and knives. If possible, the workshop should also have a minimum set of power tools: a circular saw, a band saw or a jig saw heavy enough for work without breakdown, a drill press with attachments, and a grinder. If the teacher knows how to use a metalworking lathe, he should by all means have one available. If he cannot get power tools, he can use those in the industrial-arts shops of the school.

The important thing is that the teacher have the supplies at hand to keep his equipment in good repair and to make devices for demonstrations. The cost of hand tools, power tools, and basic supplies such as nails, wire, screws, bolts, metal, glass, and wood is far below that of ordering expensive equipment and allowing it to deteriorate on the shelves or in the laboratory. Most administrators can be brought to see this and to understand how difficult it is for the busy science teacher to rush down to the industrial-arts shops to borrow hand tools or to use power tools.

SCIENCE ROOMS

Little is gained by discussing the ideal science room. Most teachers must put up with the size and general design of the rooms they inherit. But a word about a functional science room or suite science of rooms may be in order. The reader may someday have the opportunity of working with architects in designing rooms for a sound science program. And he may have the chance to make some major changes in the arrangement and design of the room space he already has.

The keynote of modern design for science rooms is flexibility. Modular units and movable desks, shelves, worktables, and chairs are highly desirable. Ideally, a science room should include provision for the total offerings of the science course, including discussion, lecture, demonstrations, and experimentation. It should have adequate storage space and workshops adjoining it. It should provide for certain fundamental operations pertinent to the specific field. For example, the biology room should have access to an adjoining animal room and a room for growing plants. The animal room should be well ventilated and equipped for experiments in genetics, diet, and so forth, as well as for the maintenance of animals and their food supplies. The plant room should obviously provide for direct sunlight and have ventilating sashes for heat and moisture control. The physics room should have an adequate darkroom for photographic work and light experimentation. The chemistry room should have a separate and accessible room for advanced work in quantitative analysis.

But, again, the keynote should be flexibility. An inspiring, well-trained, and dynamic teacher can do much in a barn of a room and with little equipment. But he can do much more if he has adequate supplies and the space for the flexible employment of his equipment in a flexible and functional program of instruction. The good teacher will work constantly for the improvement of the setting in which he offers his instruction. The "ideal" science room does not

exist as a concept. The ideal science room is the most functional room that a teacher can create out of clearly seen objectives, knowledge of the instructional process whereby these objectives can be achieved, and the basic room shell and facilities he inherits or can get. The ideal classroom grows out of a teacher's clear understanding of his function and how he wants his instruction to go on. It is never found in a book. He may get good ideas from books, but he must create his own facilities just as he must develop his own instructional plans, resource units, and teaching procedures as he grows on the job and finds what works well for him.

THE RESEARCH ROOM AND THE GIFTED STUDENT

Very few laboratories in the nation are adequately equipped. Administrators and school boards provide large sums of money for gymnasiums and sport equipment. They often budget with reasonable adequacy for shop work and home economics. But the science department is generally underequipped and underfinanced. To a large degree, this is the fault of the science teacher. He too often is incapable of making a good case for adequate room space, supplies, and equipment. He cannot expect the administrator, often untrained in science, to see the value of spending more money for science instruction if the science teacher himself is rather vague on just what he needs and what he will use his materials for.

One of the biggest needs in modern science instruction is space and equipment to facilitate the educational growth of those youngsters who have a flair for science. Gifted students should have at their disposal a research room and equipment for the construction and manipulation of a wide variety of apparatus. A few schools have made provision for such rooms. Typically, such a room has a good set of hand tools, power tools, and basic supplies similar to those suggested for the teacher's workshop. In addition, they have adequate storage space and worktables for approximately ten students (the number, of course, will depend on the size of the general school enrollment). Students who are properly qualified by training in science courses and by aptitude and willingness to accept responsibility are permitted to engage in long-range projects in such a room. Often these projects go on year after year (see Chapter 14). Each hour of the day some one responsible student is given charge of the research room. He has the responsibility and is delegated the authority to control the use of the room and to see to it that serious work is done without horseplay. Each student who is permitted to use the room is given a pass signed by the science teacher. His freedom to use the room is conditioned on the degree to which he does serious work, which is determined by individual conferences with the science teacher, written reports of progress, and weekly seminars with the other like-minded students who are given the opportunity to work in the research room.

It is important, of course, that the teacher spend as much time as possible supervising the work of students in the research room. This supervision should be counted as part of the teacher's load.

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A partial listing of the table of contents will indicate the usefulness of this little book. "How to Organize Your Science Club," "Activities for your Science Club," "Projects Your Science Club Can Undertake," "Science Service Aids for Science Clubs," "Free and Low Cost Materials for Science Clubs," "Recommended Books for Science Clubs."

SUTTON, RICHARD MANLIFFE, *Demonstration Experiments in Physics.* New York: McGraw-Hill, 1938.

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UDANE, BERNARD, AND HERMAN W. GILLARY, *Student's Handbook of Science.* New York: Frederick Ungar Publishing Co., 1948.

Several copies should be in the room library. Packed with helpful suggestions on the nature of science, careers in science, the school's offering of science courses, how to study science, and the techniques and materials needed for a wide variety of science hobbies. Excellent bibliography on hobby books.

NOTE: In addition to the foregoing the teacher should add to the room library a number of the excellent books written for children which include demonstrations and experiments. Write to the various publishers for literature or examination copies of such books. Or see R. Will Burnett, *Teaching Science in the Elementary School* (New York: Rinehart & Company, Inc., 1953), for an annotated list of children's books in each aspect of the biological and physical sciences.

Periodicals

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Turtox Service Leaflets. General Biological Supply House, 761-763 E. 69 Pl., Chicago, Ill.

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9

AUDIOVISUAL AIDS AND SCIENCE INSTRUCTION

If we were to say that *mole poblano* is a dish to titillate the palate of the most discriminating gourmet, your reaction would depend heavily on your background of experience with Mexican cooking. If you have never eaten *mole poblano,* the statement would be almost meaningless to you. But, if you have eaten this exotic dish, which is made of chicken and a sauce that includes a variety of pungent spices, the statement would evoke recollection of the original experience. One can hardly remain indifferent or neutral about the taste of *mole poblano.* You are likely either to enjoy the dish very much or to find it quite distasteful, for the eating of *mole poblano* is quite a gustatory experience.

If the science teacher or a textbook were to suggest to a student that carbon monoxide may be prepared by the dehydration of formic or oxalic acid by sulfuric acid, the student's reaction will also depend upon whatever experiences his mind can evoke. To many youngsters, such statements as this are esoteric jargon and may forever remain vague and meaningless; for, to many youngsters, many things that are taught are merely words, symbols without reality in direct and vivid experiencing. If the student has prepared carbon monoxide in the laboratory, or if he has seen its preparation demonstrated by the teacher or another student, the verbal symbolisms of its preparation may take on real meaning. But if he has never witnessed its preparation, or has never had sufficient experience in actually observing the process of dehydration with other chemicals, he can develop at best but a verbalistic command of the words which symbolize the process.

It is surprising how commonly science teachers forget this fundamental fact. The science teacher who is well trained in his discipline seems to forget the long

process of experiencing by which he has become familiar with the facts, laws, and mathematical expressions of laws in his field of expertness. To him it seems almost self-evident that a monobasic acid is one having one replaceable hydrogen atom per molecule; or that the prophase of mitotic division precedes the metaphase; or that work, in the physical-science sense, is the product of force multiplied by the displacement of the point of force application in the direction of the force. But not to the student! He may be taught to use the words and to develop some facility in the verbalistic juggling of the words. But unless he is given concrete and meaningful experiences in the reality that lies behind such expressions he will not have learned what the words refer to. One must actually eat *mole poblano* to know what the words *really* mean. One must experience science phenomena at least vicariously in order to have any real understanding of the facts and principles expressed through the symbols of reality we call words.

The present chapter deals with the wide range of instructional devices that are less symbolic than printed or oral words. It suggests the wealth of these devices and how the science teacher may put them to use to provide experiences more or less directly based upon the world of reality.

This is not to suggest that the printed and oral word should be neglected. On the contrary! Man is capable of abstract learning and of understanding symbolism. Unless the student can develop precision in the use of language, he will be incapable of critical thought. But language usage must be built upon experiences that give vitality to the words. The job of the science teacher is, therefore, to help his students learn from direct experiencing, vicarious experiencing, *and* from written and oral expression.

The laboratory provides one of the most satisfactory opportunities for direct experiencing. Science teachers know this, and few would attempt to teach science without a laboratory. For certain purposes, field trips in which objects, phenomena, and events can be observed in their natural settings are necessary for real and durable learnings. But there are other important learnings for which the laboratory and the field will not suffice. To assist the teacher, there are objects, specimens, models, motion pictures, flat pictures, charts, maps, graphs, lantern slides, filmstrips, recordings, radio, and television. The laboratory and field trips are considered in Chapter 8. This chapter offers suggestions on the use of other categories of audiovisual aids.

EVIDENCE OF THE EFFECTIVENESS OF AUDIOVISUAL AIDS

There can be no question about the effectiveness of the proper use of visual aids. A motion picture shown in the school's auditorium without student preparation or follow-up is generally a complete waste of instructional time. A preserved specimen, hurriedly demonstrated from the front of the room to a classroom of youngsters who are unprepared for the learnings potential in the specimen, may

not be worth the formaldehyde in which it is kept. But the limited research studies that are available indicate that audiovisual aids properly used as an integral part of the total teaching situation have the following values.

1. They are highly motivating and develop a great amount of student interest.
2. They contribute to understanding and meaning and, therefore, even to an increase in vocabulary and verbal facility.
3. They reduce verbalistic learnings and promote conceptual thinking by providing a basis of concrete reality.
4. They often appear to have made learnings more durable.
5. They provide experiences of things and processes that cannot be experienced otherwise.

As stated in the *Encyclopedia of Educational Research,*[1]

> Significant gains have been reported in informational learning, retention and recall, thinking and reasoning, activity, interest, imagination, degree of assimilation, and personal growth and expression; and these results have indicated a saving of time both in preparation of work and in completion of minimum essentials.

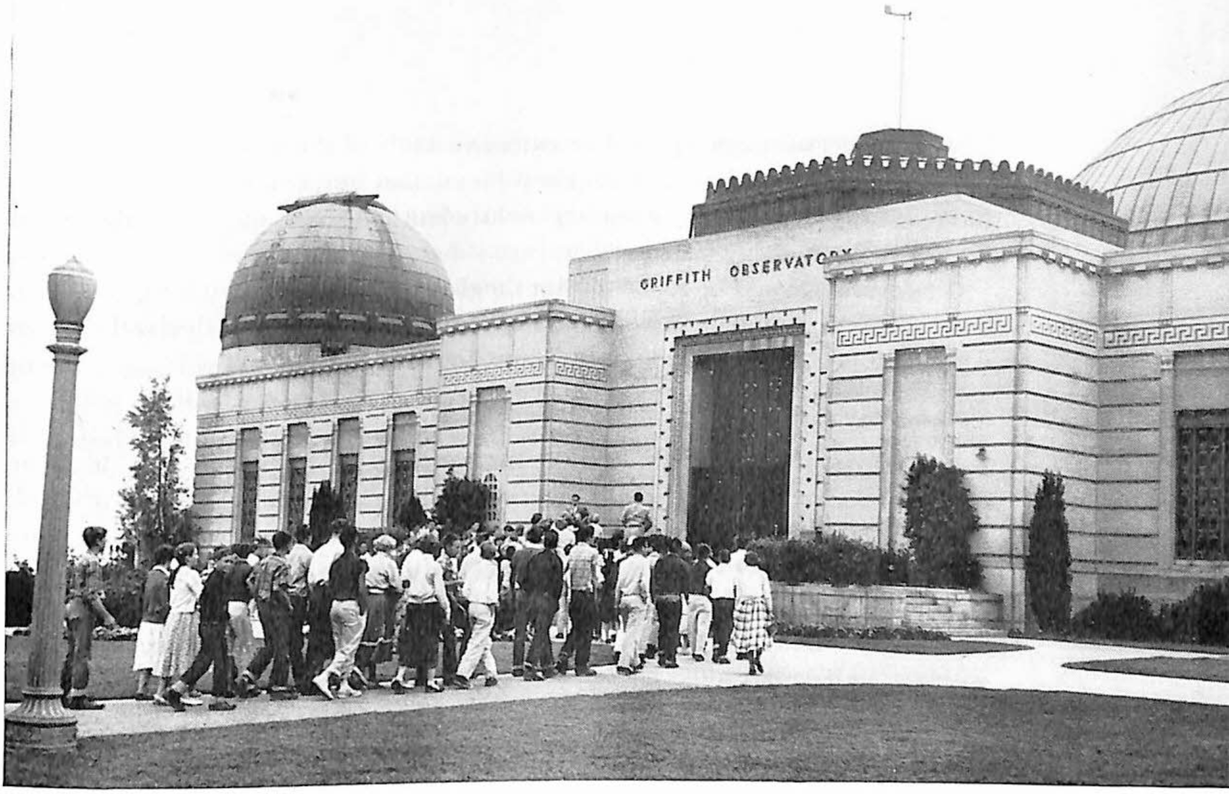
The research that lies behind this statement and makes it tenable is voluminous and can be only briefly surveyed in this volume. The reader is urged to read the reference works suggested in the Appendix for a fuller account of such research and the proper use of audiovisual aids in the classroom.

The Motivating Power of Audiovisual Aids

Suppose that a science teacher is interested in teaching his students the facts about our national problem of soil conservation, and that he is aware of the necessity of motivating his students to really want to learn and to do what they can about the problem. If he were to teach them entirely by the verbal route he would have his hands full even keeping the youngsters interested enough to stay with their "lessons." But if he were to utilize such excellent films as Pare Lorentz' *The Plow That Broke the Plains* and *The River,* if he were to go with his students to measure soil runoff in the field, and if he were to help his students record and measure gullying or sheet erosion, he would have his students, as a group, so shocked and concerned with the problem that he would later have difficulty terminating the unit. This is not idle conjecture. It is a matter of repeated record in schools all over the country. But one need not accept the statement at face value. There are objective data attesting to the motivating power of audiovisual aids. The following are a few of the studies that bear out this statement.

During World War II the Army undertook a number of studies of the effective-

[1] Edgar Dale and others, "Audio-Visual Materials" in Walter S. Monroe (ed.), *Encyclopedia of Educational Research* (New York: The Macmillan Company, 1952), p. 85.



The motivating power of visual aids is well known. Their proper use, however, requires careful articulation with the total instructional program. Careful planning is particularly necessary if fullest values are to be realized from field trips or the use of outside visual resources. (Courtesy of Los Angeles Public Schools)

ness of an orientation film *Prelude to War.* These studies utilize a group of inductees, who were shown the film, and a matched control, group who were not. By every measure used, the film was effective. Those soldiers who had seen the film were more likely to believe that they knew what the fighting was all about and therefore, of course, more likely to do their part willingly in the war. They actually had more information about the war and showed evidence of higher morale than did the matched control group.[2]

Knowlton and Tilton[3] studied the amount of voluntary reading done by seventh-grade pupils in connection with the use of films. They found that the use of films increased student participation in recitation and discussion. Voluntary reading in the classroom by the film group increased to far more than that by the control group, which was taught by the usual classroom instructional procedures. It is interesting and somewhat paradoxical, however, that there was no increase in voluntary reading done outside the classroom.

[2] C. F. Hoban, *Movies That Teach* (New York: The Dryden Press, Inc., 1946). See also J. R. Miles and C. R. Spain, *Audio-Visual Aids in the Armed Services* (Washington: American Council on Education, 1947).

[3] D. C. Knowlton and J. W. Tilton, *Motion Pictures in History Teaching* (New Haven, Conn.: Yale University Press, 1929).

Wood and Freeman[4] reported an extensive study of the use of films in connection with classroom instruction. They found that student interest was greatly increased and that voluntary reading and student participation in class discussion were both significantly increased.

Other studies could be reported. But the reader has but to recall his own experiences either as a student or a teacher to confirm the fact that audiovisual devices, when well selected and used, have compelling motivation value.

The Learning and Retention of Factual Material

If audiovisual aids can motivate the student to learn, and if they provide meaning and substance to what would otherwise remain symbolic and vague, it would be logical to conclude that they would promote more efficient learning and more durable learning. Research evidence supports this conclusion. The studies have usually incorporated audiovisual aids in classroom instruction for certain groups of youngsters and have provided control groups with comparable instruction but without audiovisual aids. Unfortunately, most of these studies have been concerned with the educational film, and the data concerning other types of auditory and visual aids is extremely meager. Studies made by Arnspiger,[5] Mount,[6] and Watkins[7] are particularly worth the science teacher's attention. Mount and Watkins deal specifically with science instruction. All these studies showed greater factual learnings when motion pictures were employed in the instructional program.

Studies of retention have shown a significant superiority of the instruction which incorporated the use of audiovisual aids over the instruction which did not employ such aids. Gatto[8] experimented with the use of visual aids in teaching geography. He determined the mean scores of his student groups directly following instruction and after five weeks. The students who had been instructed without the use of films dropped 11 per cent in the group mean score after five weeks, while the film-group mean score *increased* 11 per cent after five weeks. An increase in scores on a factual test may be surprising to the reader. But various studies of retention have shown that there is often a maturation (possibly aided by additional out-of-school learnings following the period of formal instruction) which results in an increase rather than a decrease in scores.

[4] F. N. Freeman and B. D. Wood, *Motion Pictures in the Classroom* (Boston: Houghton Mifflin Company, 1929).

[5] V. C. Arnspiger, *Measuring the Effectiveness of Sound Pictures as Teaching Aids*, Contributions to Education No. 565 (New York: Bureau of Publications, Teachers College, Columbia University), 1933.

[6] James Nathaniel Mount, "The Learning Value of Motion Pictures in High School Physics as Compared to the Use of Supplementary Textbooks (Master's thesis, University of Washington, 1931).

[7] R. K. Watkins, "The Learning Value of Some Motion Pictures in High School Physics and General Science as an Illustration of a Simplified Technique in Educational Experimentation," *Educational Screen*, 10:135–137, 156–157, 1931.

[8] F. M. Gatto, "Experimental Studies on the Use of Visual Aids in the Teaching of Geography," *Pittsburgh Schools*, 8:60–110, 1933.

Results similar to those of Gatto were found by Rulon,[9] who measured the retention of facts of film and nonfilm instructional groups in science classes. He found that the group which had been instructed through educational films incorporated into the learning process had learned more than the nonfilm group when tested on immediate recall, and that their superiority increased after a time lapse. Rulon's investigation included a study of thinking ability as well as factual understanding, and the film group was superior in this as well.

Similar studies by Arnspiger,[10] Goodman,[11] Hansen[12] and others have produced comparable results.

The Development of Skills

There are almost no adequate and reliable studies that compare learnings from laboratory work with those resulting from the use of audiovisual aids. There are a few which deal with skill development. A study by Rolfe[13] showed convincingly that demonstrations in physics produced superior results in manipulatory skills compared with those obtained when a motion-picture film presented comparable phenomena.

Other studies by investigators working in nonscience fields have produced similar results. Of interest to the general-science and biology teacher are those conducted by Freeman and Hoefer,[14] and by Hoefer and Keith.[15] These two studies utilize films which dealt with diet and the care of the teeth. They showed that the film instruction was not superior to other types of instruction incorporating visual aids in developing sound habits of dental care.

On the other hand, the use of audiovisual devices in industrial-training programs has been found to produce excellent results. Brooker[16] has reported on the use of both training films and filmstrips. He found that almost all training directors in industry believe that films speed up training without loss of effectiveness.

[9] P. J. Rulon, *The Sound Motion Picture in Science Teaching* ("Harvard Studies in Education," Vol. 20; Cambridge, Mass.: Harvard University Press, 1933).

[10] Arnspiger, *op. cit.*

[11] D. J. Goodman, *The Comparative Effectiveness of Pictorial Teaching Materials* (New York: New York University, 1942).

[12] J. E. Hansen, "The Effect of Educational Motion Pictures upon the Retention of Informational Learning," *Journal of Experimental Education*, 2:1–4, 1933.

[13] E. C. Rolfe, "A Comparison of the Effectiveness of a Motion-Picture Film and of Demonstration in Instruction in High-School Physics," in F. N. Freeman (ed.), *Visual Education* (Chicago: University of Chicago Press, 1924), pp. 335–338.

[14] F. N. Freeman and Carolyn Hoefer, "An Experimental Study of the Influence of Motion Picture Films on Behavior," *Journal of Educational Psychology*, 22:411–425, 1931.

[15] Carolyn Hoefer and Edna Keith, "An Experimental Comparison of the Methods of Oral and Film Instruction in the Field of Health Education," in F. N. Freeman (ed.), *Visual Education* (Chicago: University of Chicago Press, 1924), pp. 346–376.

[16] F. E. Brooker, *Training Films in Industry* (U.S. Office of Education, *Bulletin* No. 13; Washington: Government Printing Office, 1946).

A questionnaire was sent to five hundred users of the training films produced by the U.S. Office of Education. Both industrial and educational users were practically unanimous in believing that the films developed greater interest, better understanding, and higher skills. Similar results were found in the studies conducted to determine the effectiveness of audiovisual aids in the military-training programs of World War II. It should be noted, however, that such aids were designed with precise purposes in mind, they were used in connection with other teaching devices, and the research, itself, is extremely limited. But, for familiarizing the student with manipulation processes, audiovisual aids—particularly films and filmstrips—seem to have great value. Naturally, such aids cannot do the whole job. A film may show a student how to prepare a sterile agar plate and innoculate it, but he must do the job himself before he will develop facility.

THE USE OF AUDIOVISUAL AIDS IN THE SCIENCE PROGRAM

Audiovisual aids have their proper use, and they have their distinct limitations. Audiovisual aids are one degree removed from reality, and they should never replace direct laboratory or field experiencing for fundamental learnings, unless such experiencing is impossible. All too often, teachers of science take the lazy path of ordering films and filmstrips and using them when equipment *is* available for student experimentation or demonstration.

Educational Films

The motion picture has doubtless had more overuse and more improper use than any teaching device available. In the first place, many "educational" science motion pictures are hardly educational. The market is glutted with sloppy films that have, at best, some entertainment value, and the classroom is hardly the place for entertainment movies. There are also hundreds of excellent films. But it is extremely difficult for the user to know what is sound and what is worthless when he must order from a catalogue. Fortunately, there is a growing body of information to help the teacher make his selections wisely. A study conducted by the American Council on Education secured "expert," teacher, and pupil judgments on hundreds of instructional films. Thousands of film evaluations were secured and published in a descriptive encyclopedia of films.[17] This volume should be available in the school library and used in selecting films for use in the science classroom.

Limitations. To have educational value the film should obviously be used as an integral part of the instruction. If it is to be used to motivate the class and to initiate a teaching unit, it should be employed at the beginning of the unit. If it

[17] Staff Motion-Picture Project, *Selected Educational Motion Pictures: A Descriptive Encyclopedia* (Washington: American Council on Education, 1942).

is a film that describes an industrial process, it might be needed both before and after a field trip to an industrial plant where the process may be seen. If it is a film on electromagnetic induction, it might be used several times—to provide an introduction and overview, to illustrate certain details in connection with laboratory work and reference work, to summarize the study of electromagnetic induction, and to clear up hazy concepts.

The point is that a film, like any other teaching aid, must be an integral part of a well-planned sequence of experiences, and it must be used when it will contribute to the learning process. But few schools or school systems, except those in metropolitan communities, have a sufficiently large and up-to-date film library to make such use possible. Even in the largest cities, the science teacher often must place his order for films so far in advance of the time he expects to use them that it is virtually impossible to work them meaningfully into the learning process. And, in the smaller communities, it is quite common for a class to see an "educational" film a month or more after they have completed their study of the material to which the film refers. Such use cannot be approved. Unless the teacher can secure good films and use them when they are appropriate, he would be wise to turn to audiovisual aids that are more easily secured.

Another difficulty in the use of educational films—particularly sound films—is also economic. For the best use of sound films, each classroom should be equipped with a sound motion-picture projector, a screen, suitable acoustics, and a means of darkening the room. But in most school buildings, this is impossible. Films are shown in a special room equipped for the purpose, or, even worse, the class must be taken to the auditorium. Films vary in their nature and, therefore, in the form of their proper use. Films suitable for the science class generally require showing more than once. A good film, such as *The Work of Rivers* (Britannica) or *Digestion* (Eastman), needs to be discussed and analyzed as it is being shown. In a sense, it should be cut apart. After appropriate preparatory work, the class should be allowed to see the film through without comment. Discussion after the showing will elicit questions, points of vagueness, and perplexities. The film should then be reshown but stopped as often as need be for discussion, questions, clarification by the teacher, and so forth. Such use cannot be made of films in an auditorium. If a class has to move down the hall or up the stairs and sit in a room where they also go for general entertainment, the climate will be wrong. An educational film should demand something of the student viewer. It should lead him to think, to wonder, to question. Such mind-sets and mental activities are almost impossible to elicit in an auditorium setting. In general, it is not unfair to suggest that "educational" films shown in the auditorium might just as well not have been shown at all. Among the studies which tend to support this contention are those of Knowlton and Tilton[18] and of Krasker.[19] The results of factual tests demonstrated

[18] Knowlton and Tilton, *op. cit.*

[19] Abraham Krasker, *A Critical Analysis of the Use of Educational Motion Pictures by Two Methods* (Boston: Boston University, 1941).

that classroom use of films was far superior to auditorium use. The latter use was found to be quite inefficient.

A third limitation in the use of educational films is that the sequence and continuity of learning is set by the film itself. The time may come when some producer of educational films will make available films of not more than four minutes duration which deal with a single and specific aspect of science. The typical 400-foot-reel educational film attempts to present an overview of an entire field. What is needed in addition are low-cost films which deal intensively and well with single aspects of such a field. For these to be useful, they will have to be cheap and accompanied by the availability of low-cost projectors. If this is done, the science teacher may some day be able to keep a complete file of films in his room and use them flexibly, as his program develops during the course of the semester. But few such films are available at the present time, and the teacher must show the larger, more superficial films, which include what he needs at the time and much that he would like to delete. (Coronet Films has produced a limited number of short films in science, each running for about five minutes and dealing with a single, limited subject, but these are suitable only for general-science courses in the lower grades.)

There are other limitations which are rather obvious. Films are expensive compared with other audiovisual devices. They tend to relegate the teacher to the background. They tend to create a passive rather than an active mind-set. And, above all, the film is too often used as a substitute for, rather than as a supplement to, other learning experiences which are closer to reality and which foster a higher degree of active thought.

Effective use. The advantages of educational films account, of course, for their widespread use and general popularity. We have already indicated a number of their advantages, including some of the research evidence to the point. But their advantages to the science teacher are particularly great. They will be considered briefly in connection with the following suggestions for sound film use in science teaching.

Obviously, there is no advantage in using motion pictures unless motion is desirable to illustrate a phenomenon, an event, or to provide a feeling of historical continuity. If motion is not essential to the required learning experience, still pictures or other sorts of audiovisual aids should be used.

Some sorts of motion are too rapid for the human eye to detect or so slow that they cannot be observed. Others take place under conditions in which the action is obscured, and animation is necessary. It is to illustrate such types of motion that films can be especially valuable to the science teacher.

There are many excellent films that employ time-lapse photography to illustrate in a few moments growth or other types of motion that, in nature, go on so slowly that they cannot be detected. The growth of roots and their tropistic responses, the opening of flowers, and the growth of pollen tubes through the style and down

to the ovary are examples of some of the excellent time-lapse films that are available for science instruction.

Slow-motion photography has also been intelligently used to provide the science teacher with a visual record of many motions that are so rapid in nature that the eye cannot detect them. The pictures are taken at a high rate of speed and then projected at the normal rate. This slows down the motion so that careful study can be made of it.

The experienced biology or general-science teacher knows how difficult it is to get beginning students to do successful work with a microscope. Aside from the importance of developing manipulatory skill, there is little profit in requiring youngsters to spend hours locating and attempting to see clearly microscopic objects that can be projected with a microprojector or through films. Microphotography has its place in the classroom. Still pictures will often suffice, but the dramatic effect of technically good motion pictures that show microscopic life—and which often include time-lapse photography—make them well worth employing.

But probably the most valuable films to the science teacher are those that employ animation. The teaching of electronics, of sound, of certain phases of physiology and body mechanics, to name just a few science areas, is greatly enhanced by the use of educational films that animate what exists but cannot be seen. *Sound Waves and Their Sources* and *The Heart and Circulation* (both by Britannica) are good examples of such films.

The teacher of science should not neglect the powerful documentary films and others that create moods, provide historical perspective, and expose problems that need solution. The following are examples of those available from educational distributors. *Bordertown* (Warner Brothers), which deals with the Mexican immigrant who struggles to be accepted and is struck down by prejudice, and *Don't Be a Sucker* (U.S. Army Signal Corps and available for loan from the National Conference of Christians and Jews), a film that shows the techniques used by Hitler to divide peoples, are good examples of films about prejudice that can set the stage for rewarding science experiences (see the fuller suggestions for combating prejudice through science teaching in Chapter 11). *Louis Pasteur* and *A Way in the Wilderness* (both by Metro-Goldwyn-Mayer) are outstanding examples of the power of motion pictures to recreate the historical past. The latter film is the record of Goldberger's research that led him to the discovery that pellagra is a deficiency rather than a germ disease. And we have already mentioned the tremendous power of Pare Lorenz' magnificent *The River* and *The Plow That Broke the Plains*. These two films, focused on soil conservation, are among the best documentary films for science instruction that have ever been produced. But there are many other good ones, and the teacher should preview them and incorporate those that are appropriate into his instruction.

Whatever films the teacher uses, certain patterns of use should be followed. These are necessarily general, and no set rules should be looked for here any more

than in any other aspect of teaching. The particular way a particular film should be used depends upon the previous experiences of the pupils, the teaching objectives, and the type and difficulty of the material to be presented. But, in general, the following suggestions are worth the science teacher's attention.

1. *Always* preview the film before showing it to students. A film cannot possibly be made an integral part of the learning process or used correctly and at the right time unless the teacher knows exactly what is in it.
2. Decide how and in what way the film is to be used. Certain parts of the film will need to be emphasized for particular instructional purposes, and other parts may be of little value. If the film is to have optimum value, the teacher must know, before it is shown to the class, just how he wants to use it.
3. Prepare the class ahead of the showing for the film they are to see. The film should not be shown until the class is ready for it. Some films will require extensive study and classroom and laboratory work for greatest value. Others will require but a brief analysis by the teacher of what to look for. But some class preparation is always desirable.
4. The actual showing of the film should be varied according to the objectives of instruction and the nature of the film. In general, however, science films will require more than one showing. As a general rule, it is desirable to stop the film occasionally during the second running to take care of questions, to emphasize certain points, to clarify background data, and so forth.
5. Follow up the film with other activities that will make the film part of the continuum of learning. These might take the form of a test after the showing (useful to lessen the tendency of some students to enjoy the "movie" passively.) Or the film might lead to discussion, laying plans for a unit or for gathering data, laboratory work, or a wide variety of learning activities. The important thing is that the teacher consider the film as an integral part of the educational process and that he help the students to see it in the same light.

Filmstrips and Projection Slides

Many different kinds of filmstrips (a series of pictures, charts, or other materials on a 35-mm. film) are available for science instruction. The chief advantage of filmstrips over motion pictures is that both filmstrips and the filmstrip projector are relatively inexpensive. In addition, the filmstrip can be stored in the room along with the light projector and used whenever needed without the extensive preparations so often required for sound use of motion-picture films. In the third place, the filmstrip provides far greater flexibility of use than does the motion-picture film. Although the sequence within a filmstrip is set, the teacher can easily

show a single picture or chart or any combination of pictures. And, finally, the filmstrip can be shown at the speed that appears desirable, and the entire class can discuss the pictures as they are shown. In fact, in any presentation where motion and continuity are unimportant, the filmstrip will generally produce as good or better results as motion-picture films, at much less cost and with far greater flexibility.

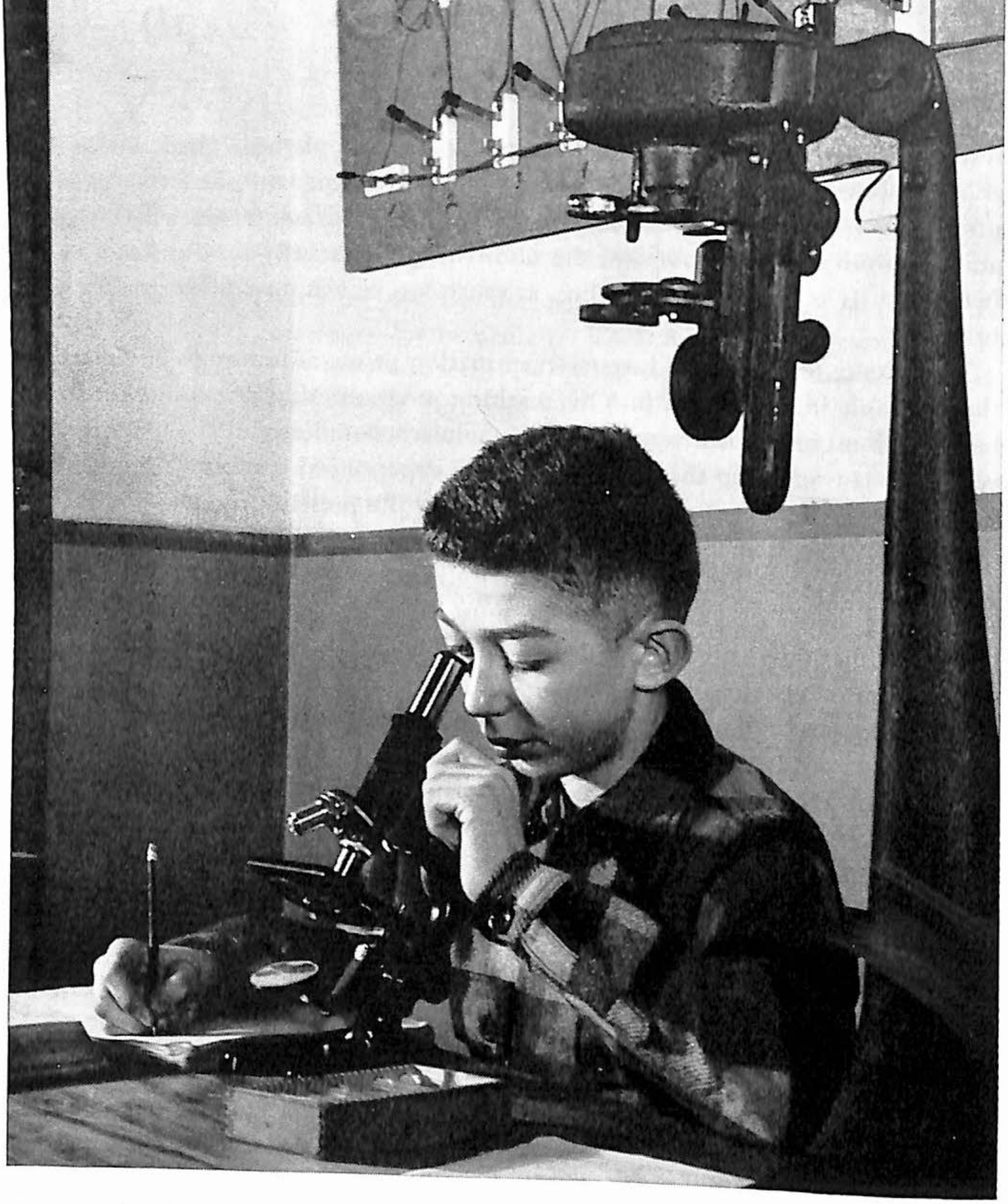
The science teacher should secure examination prints of filmstrips and consider their possible incorporation into his teaching program. Many examination prints have excellent manuals designed to help the teacher understand the material and various means of using the filmstrips. The inexperienced teacher will find these valuable, but these tend somewhat to stereotype the presentation and should not be followed slavishly. In general, the five suggestions for using educational films are also appropriate for the use of filmstrips. Filmstrips, like any other teaching aid, are supplementary materials that must be fitted integrally into the total learning situation.

Most filmstrip projectors will also project 2-by-2-inch slides. These slides, if well catalogued, provide even greater flexibility of educational use than the filmstrip, for a teacher can use a single slide or any number of slides in whatever order he chooses. This is often a decided advantage in a dynamic learning situation. And of no small advantage is the fact that the teacher can make his own slides from photographs taken with a 35-mm. camera. This opens up a wide avenue of excellent possibilities for visual instruction. Pictures, charts, demonstrations, museum and industrial materials, microphotographs, and pictures that show stages in laboratory work or field experiments are among the possibilities.

Lantern slides and opaque projection should also be mentioned. Lantern slides preceded the 2-by-2-inch slide, and far more complete scientific materials may be obtained on these than on the 2-by-2-inch slides. Furthermore, almost all high schools have one or more lantern-slide projectors available together with slides that have accumulated over many years. If these slides are well catalogued, they can contribute materially to science instruction. Many lantern-slide projectors will also project opaque pictures, and there are times when materials from current scientific publications or such magazines as *Scientific American* and *Life* can be put to good use. However, a better practice is to photograph such materials with a 35-mm. camera and to project the slides. The opaque pictures quickly become dog-eared and crumpled, and it is difficult to secure enough light for clear identification of all the details.

Microprojectors

Compound microscopes are expensive and so are the prepared slides for their use. Every general-science and biology class should have several for the individual use of students. But it is doubtful whether it is necessary or even desirable for every student to have access to his individual microscope. Certainly, when the initial cost of equipment, plus the cost of repairing objective lenses, is compared



Compound microscopes and microprojectors both have their advantages. For general education programs operating under limited budgets, a good microprojector may be the best choice. (Courtesy of Cleveland Public Schools)

with the cost of a single good microprojector, the practice of providing a compound microscope for each student becomes highly questionable. Advanced courses in the biological sciences should, of course, utilize good microscopes for each student. But microscopic technique is rarely learned in beginning high school classes, and, in any event, can wait until the student has entered college classes.

The uses of a microprojector. Whether or not the school has microscopes for all the students enrolled in biology, it should own a good microprojector. If it can

be afforded, it would be well for the school to purchase both a low-power, inexpensive microprojector (preferably one of the types which can project from a horizontal stage, so that live mounts can be projected) and a really good compound-microscope projector. With such equipment, the teacher can present a wide variety of living microscopic specimens, prepared slides of tissues, cells, organisms, and so forth. If his class is working with microscopes, he can use the microprojector to point out and emphasize those things that are of importance in the slides they are using. Quite often, one student in the class will find an unusual specimen or will have a slide that shows certain features particularly well (stages of mitotic division, for example). The teacher can project this slide so that the entire class may benefit.

The construction of a microprojector. Good microprojectors are expensive. The teacher can construct one which will provide reasonable satisfaction. The materials required are a source of light, a cooling cell, a compound microscope, and a condensing lens. The light source should be an electric arc (which can also be made), but a 500-watt or 750-watt projector lamp will work. The electric arc provides far better illumination, however, and it is worth the trouble of making it (and keeping it working) to have the better lighting of microscopic specimens.

The electric arc can be used in other science instructional work where an intense light source is needed. It is made from two pieces of 1/4-inch-diameter cored carbon rods, a 600-watt resistor, which can be purchased (the cone of a radiant heater works excellently), and a supporting board made of asbestos.

The asbestos board should be approximately 4 inches high and 6 inches long. A rectangular section about 2 inches by 2 inches should be cut out of one side. The carbon rods are mounted to the asbestos board by pieces of sheet metal. These are bolted to the board so that the rods are held firmly but so that they can be moved toward each other or apart. The asbestos board is then fastened to a wooden base with wooden cleats. The 600-watt resistor is fastened to the same wooden base. The resistor and the two rods are wired in series with insulated wire. The carbon rods are wired by running the insulated wire around the shafts of the bolts that hold the rods to the sheet-metal clamps. To prevent receiving shocks in adjusting the carbons, the outside end of each should be wrapped with several turns of plastic or friction insulating tape. The circuit is connected to a 110-volt line, and the tips of the carbons are brought into contact. When they are pulled slightly apart, an intense arc of light is produced. When the arc falters as the rods are burned away, the rods should be slid closer together again. If the arc fails entirely, the rods should be again brought into contact and then pulled slightly apart.

The brilliant arc can injure the eyes, so it must be housed in some kind of cover or shield. A suitable one can easily be cut from a large tin can. A hole 2 inches in diameter is cut from one side at the correct height to provide a light opening for the arc. Another ventilation hole, about one inch in diameter, is cut in the top of the can. A heavily smoked piece of glass should be used when looking down at the

arc in adjusting the carbon rods, so that the eyes will not be injured. Holes slightly larger than the diameter of the rods are punched into the sides of the can so that the rods may be moved together or apart.

The microscope is placed horizontally upon a suitable stable surface. The mirror is removed or swung out of the way. A convex lens approximately 4 inches in diameter is used for the condensing lens. It is mounted on a block of wood or laboratory clamp so that it can be moved back and forth. Between the arc and the lens is placed a cooling lens. (This is necessary to protect slides and the microscope lens from the heat of the focused light beam.) The cooling lens may be made from a straight-sided glass bottle of clear glass. This is filled with water or a 0.5 per cent by weight solution of copper sulphate and tightly stoppered. The arc or incandescent lamp is placed in position so that the focused beam enters directly through the center of the objective lens of the microscope. It is necessary to adjust the light source so that this light beam strikes directly through the barrel of the microscope and into the center of the eyepiece as well.

To use the microprojector, a slide is placed on the microscope stage and the objective lens is visually adjusted for the same focus as used in ordinary work. The carbon arc or other light source is turned on and focusing is done by moving the eyepiece slowly away from the objective lens.

Adjustment for size and distance are made by moving the screen and further adjusting the eyepiece. If a larger image is desired, the screen must be moved farther away from the microprojector. If the lighting is too dim, however, the screen must be moved nearer the projector, and, of course, the size of the image will be consequently reduced.

If it is necessary to project living specimens the equipment will have to be modified slightly to allow for placing the slide on a horizontal stage. This can be done most simply by focusing the light so that it hits the mirror under the stage of the microscope and placing a 45-degree-angle glass prism upon the eyepiece. The prism refracts the light horizontally and onto the screen.

Other Audiovisual Aids

There is a wide variety of audiovisual aids to assist the science teacher in making his instruction vivid and meaningful to the student. These range from the indispensable blackboard to radio and television. The use of some of these aids is too obvious to require discussion. But some of the newer aids—and many of the older—are often neglected or improperly used.

FILING AND USING "FUGITIVE" MATERIALS

Too often science teaching looks only backward. Textbooks are slow to add newer material and to drop material that has been of little usefulness for decades. The basic principles do not change, of course, except as newer knowledge modifies them (as in the case of Newtonian physics or theories of radiation and the trans-

mission of light). But textbook after textbook continue to devote space to a variety of lift and force pumps, although few youngsters today have much interest in lifting water from a cistern. It is in the choice of examples of basic physical principles that textbooks are often seriously at fault, and, as has been suggested in another section of this volume, they too often seem to confuse the principle with the examples.

It is almost impossible to realize the values inherent in science teaching and to achieve the broader objectives suggested in Chapter 1 through the single use of a textbook. And, fortunately, there is no need to try. There are many sources of excellent materials which the teacher can obtain free or at nominal cost. These include publications of the federal government, state governments, professional scientific organizations, public and private organizations devoted to the advancement of various causes (the many health organizations, such as the American Heart Association, for example), and trade associations and industrial firms. From each of these sources, the science teacher can obtain many excellent reference materials and visual aids.

Then, too, there are excellent publications dealing with scientific subjects. These range from the presentations in such popular magazines as *Life* to the highly dependable articles in *Scientific American*, which present lucid analyses of frontier work in science, and the technical articles appearing in various periodical publications of the scientific associations, such as *Science* and the *Scientific Monthly* of the American Association for the Advancement of Science.

Securing such materials is much less a problem to the average teacher than selecting, cataloguing, storing, and using them. The very fact that there are so many materials creates the chief problem, for a collection of such "fugitive" materials can become almost worthless because of its bulk, unless the teacher has developed some system that is efficient for selecting, storing, and using them.

One method, which the author has found to be highly satisfactory, is to utilize the services of the students themselves, either in connection with classwork or through the science club. See Chapter 14 for a more detailed analysis of the contributions of science-club activities to science instruction.

The teacher should not consider the use of students for such work to be exploitation. If properly integrated with the on-going school work, such activities can have the highest educational values. Let us suppose that a science teacher has just begun teaching in a particular school. As a unit is begun and the class structures the problems that appear to merit investigation, the need for reference materials becomes clear. With the teacher's help and the use of catalogues and reference guides to periodical literature and books (see the Appendix for a list of these), students locate sources of materials, both in the school and local libraries and from outside agencies. The work of securing such materials and studying them for suitability and reliability is divided among the students according to the particular phases of the problem in which they have interest and have accepted responsibility. Letters are written under the teacher's general supervision, materials are

secured, and their pertinency and authority discussed. As a student studies the materials for which he is responsible and presents his data for the consideration of the class, he is also expected to catalogue the materials and to place them in a permanent general file.

The cataloguing of the materials is done on standard 3-by-5-inch index cards or on half sheets of bond letter paper. At the upper left-hand corner of each card or sheet of paper is placed the general category of the material (for example, *astronomy; light; protozoa; disease, physical; synthetics*), and at the upper right-hand corner is placed the more specific subject (for example, *stars, radio; photons; Mastigophora, Euglena; poliomyelitis; silicones*). As the files grow with the years, it becomes necessary to subtitle many of the subjects. For example, it might be desirable to place the *silicone* cards under such subheadings as would indicate their particular uses or properties.

The index cards are filed in appropriate boxes (ordinary cardboard shoe boxes serve excellently if the budget is a problem) and arranged alphabetically. A master sheet for each general subject is prepared, and students are responsible for bringing these up-to-date each time a new entry is made. Each index card provides a brief record of the item to which it refers. The exact source in approved bibliographical style is given, as well as a brief description of the material. This is followed by quite brief critical appraisals of the material made by not less than two students. Later on, as other students use the filed materials, they are expected to add their own brief critical appraisals if they find the appraisals listed are inadequate or misleading.

The materials themselves are filed in various ways according to their size, shape, and bulk. Some are placed on book shelves in the room, where they are arranged alphabetically according to major subject and sub-subject. Others (particularly tear sheets from magazines and journals, single-page diagrams and other illustrative material from industrial firms, and so forth) are stapled to cardboards of uniform size and are kept in large cartons and even orange crates.

Until the teacher has tried this system of securing, evaluating, and storing fugitive materials, he can hardly appreciate the wealth of material that soon develops or the great value these materials have in science instruction. In another section (see Chapter 8), consideration was given to the critical use of such materials in laboratory work and through science-club activities. But it is necessary to emphasize at this point that the students who do the work are stimulated to careful and critical study of the materials, because the other students, as well as the teacher, require that only sound and useful materials be catalogued and placed in the files. The students are, of course, immature. In many fields, it is almost impossible for them to know what is valid and what is worthless. But this is precisely the point. Preoccupation with a single textbook or even the use of occasional reports cannot develop critical maturity in the students. But when a student is helped to understand how important it is to check one author or one publication against other authors and other publications, when he discovers—as he soon does—that there are many different interpretations given to

certain facts and even differences of opinion on what are the facts, his critical awareness grows by leaps and bounds.

The teacher's role in developing this critical mind-set is, of course, a dominant one. He must help the students develop an understanding of the procedures of critical reference work, but he must also hold them accountable to high standards of performance. The interesting thing, in the author's experience, is that the students themselves soon become the most severe critics of each other. Not all of them, of course. But when a group-designed study project is under way, and a particular student lets the group down by not knowing the material for which he was held responsible or by reporting on an obviously invalid article, the group censure tends to be rather rough. The disciplining of this criticism by the peer group is infinitely more effective than twice the amount of teacher censure. The child cares far more how he is accepted by his peer group than what the teacher may think about him.

THE USE OF BULLETIN BOARDS

Have you ever been in a science classroom and found a large bulletin board with one or two obviously ancient and dusty tear sheets or pictures hanging limply from rusty thumbtacks? If you have not, take a trip to four or five classrooms, and you are almost certain to run into at least one such room.

The bulletin board should be put to much better use. It should be kept topical, attractive, and even dramatic. This becomes an impossible chore for the science teacher if he attempts to secure materials and keep them topical without student help. But if he has developed the system of securing and filing fugitive materials, suggested in the previous section, he will find the job easy.

He need not do the job entirely by himself, of course. As a matter of fact, most classes taught according to the newer methods of group analysis welcome the suggestion that responsibility be divided among them to keep the bulletin board up-to-date and attractive.

The bulletin board need not be used only for flat displays. If a table is placed beneath it, models, working displays, specimens, student-made dioramas, and similar educational and attention-compelling materials may be attached by paper ribbons to exploded diagrams, flow charts, labels, industrial pictures, printed accounts, and so forth, to which they refer.

One of the most discouraging facts about science teaching today is the low enrollment in the physics and chemistry classes (see Chapter 1). Such displays made by students, coupled with classes that are really interesting and dynamic, form the best possible inducements for qualified students to enter the science courses. In school after school where science instruction has come out of the doldrums and is an exciting, stimulating experience for the students, the enrollment in the elective sciences has increased considerably in a matter of two or three years. One of the errors of modern education is the belief that a course must be "easy" for the students to like their instruction and stay with it. Students

Bulletin boards should be kept topical and attractive. Coupled with models, working displays, and student-made projects they can be sources of instruction supplementing the curriculum. They can be placed in a school corridor and maintained by qualified students before and after school. (Courtesy of Santa Barbara Public Schools)

really like to learn! This statement may surprise some experienced science teachers, but it is a fact. Students really like to learn. They do not like to learn nonsense syllables or learn about things that are meaningless in their lives. But it is possible to stimulate young people so that they want to learn and will work hard to accomplish the desired learnings. It takes some doing, however. The bone-dry lecture won't do it. A rote process of instruction from a single text paced to the abilities of the "average student" (who in reality does not exist) won't do it. But a living program of meaningful experiences that go intensively enough into a subject so that it is really understood and savored will do the trick every time—for the majority of the students. There will always be a few students who cannot be stimulated to experience the satisfaction of good workmanship and the thrill of fundamental understanding. But, if the teacher of science has created a situation where both the slow and the rapid have materials to work with that they can understand and profit from, he will also have a situation where the great majority are working at high levels of learning. The use of

audiovisual aids integrated into a learning situation that is purposeful, group-planned, and dynamic will produce such a situation.

Attention could be given to other forms of visual aids. The uses of recordings, radio programs, and television are particularly of potential value in science instruction. But these are subjects for expanded discussion beyond the scope of this book. There are excellent books on the subject. It must be emphasized, however, that some audiovisual aids—and records, radio programs, and television programs in particular—tend to place the teacher in the background and the student in a passive situation, and can disrupt developmental learnings. Audiovisual aids can contribute mightily to the science program and should be brought into as close a relation as possible to the program of instruction. The fact that radio and television programs—except closed-circuit programs or broadcasts and telecasts designed particularly for classroom use—cannot be previewed or utilized at times most appropriate in the instructional program make it particularly difficult to derive sound educational values from them. Nonetheless, the opportunities which such mediums present for bringing accurate, up-to-date, and dramatic presentations of modern science at work to the student indicate that the science teacher should be alert to programs as they appear and encourage his students to listen to or view them. An excellent plan for the science club would be to "treat" all students interested in science to the outstanding programs that appear on television from time to time or to such science series as may be available on local channels. A local merchant can usually be persuaded to bring a television set to the school for such uses if the school does not own a set.

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See also the material on audiovisual aids to be found in many of the reference materials suggested for Chapter 8.

10

DIAGNOSIS AND EVALUATION

One of the reasons that so many teachers concentrate on the limited objectives of factual memorization is that facts are easy to test for, and the larger objectives of functional knowledge, critical thinking, and attitudes are extremely difficult to test objectively and reliably. There is almost an indirect relation between the importance of our teaching objectives and our present ability to evaluate them accurately. As the validity of instruments and techniques designed to test these larger objectives go up, the reliability with which they test goes down.

THE PURPOSE OF EVALUATION

But the purpose of evaluation is to determine the success of the teaching and the learning. If the teaching has been directed toward the development of disciplined intelligence and social-emotional maturity, then every effort should be made to test whether these results are being attained. Because of the difficulty of evaluation many teachers have allowed their objectives to be corrupted. They start with the high purpose of making their science a living force in the lives of their students. But they are under the necessity of giving letter grades. They may have a fair understanding of what is happening to the growth of their students but these are subjective impressions unsuitable for passing or failing or grading students from A to F. It is easy to develop formal objective tests in which the student fills in blanks. It is not easy to develop good tests of this sort, but any teacher can make up a test that is at least usable. So the teacher makes such

tests or uses tests that accompany texts and workbooks. Or he secures standardized objective tests. Few of these are valid in terms of the important objectives for which the teacher is teaching. Critical thinking is largely ignored in favor of facts. But the teacher gives the tests, grades the students, and reports whether they are A or C students—whatever that means. To his distress, the teacher finds that many of the simple facts he thought his students had learned have already been forgotten. So he spends a little more time on discrete factual teaching. He tests again. He is surprised to find that his students still have somewhat startling gaps in their knowledge. So he works even harder to see to it that his students learn the facts of the science. It doesn't seem to do much good. He drills, he exhorts, he tries sarcasm. And he tests. As the years go by, the teacher is eventually found teaching rotely and cynically for as much accumulation of facts as he can get across to his students. If the teacher is aware of the research on retention and of the distinction between factual recall that is sufficient for passing examinations and factual knowledge that is durable and functional, he attempts to stuff that awareness down in some mental pocket and forget about it. If he recalls what he once knew about the nature of learning, he tries not to let that bother him too much either. For hasn't he demonstrated to himself that even teaching for factual knowledge is a tough task?

Precisely! Teaching only for facts—discrete, logically organized facts that have little or no reference to the powerful motivations of self-purpose, backgrounds of experience, and interest—is a tough task. Theory, logic, common sense, experience, and research conspire to demonstrate that even the discrete facts will be far more efficiently learned and better retained when they are brought into a framework of activities that are meaningful to the student and that provide experiences that resolve problems that are real to him, experiences that are conducive to the development of the understandings, skills, and attitudes which are a part of what we have called disciplined intelligence and maturity. But what can the teacher do when it is so difficult to test for such things? He must first recognize the nature of evaluation and consider what purposes it serves. Evaluation is more than mere testing. It is more than a technique for assigning grades.

Diagnosis for the Improvement of Instruction

A cabinetmaker, tinsmith, or mechanic tests his successes on the basis of how well he has done his job. True, a cabinetmaker cannot make a fine piece of furniture from a poor piece of yellow pine. At least, it will not be as fine a piece as if he had used fine hardwood. But a good cabinetmaker considers his raw materials before starting his construction. He considers their potentialities and works skillfully with what he has. If he fails in what he attempts, he does not blame the wood he used, for, if he is competent, he will have considered his raw material in advance, studied it for its potentialities, and used the techniques appropriate for shaping it into a thing of usefulness and beauty. The artisan who works with inert materials does not evaluate his product to assign it a grade;

he evaluates in order to diagnose his own level of success or failure and to improve his techniques.

Obviously the situation is somewhat different in teaching—but only somewhat. The teacher works with living, sensitive, and often apparently intractable young people. The teacher can build a case for the proposition that he could have done wonders if only the youngsters were willing to learn or if he had really bright youngsters to work with instead of "these knuckleheads." A case can be built, but it is not much of a case when examined. It is fair enough for the teacher to evaluate his students and to devise some system of communicating his findings. It is even appropriate for the teacher to place some of the blame for failure in learning on the students. But is not the teacher as much as the cabinetmaker responsible for careful diagnosis of his "raw material" and for the best and most artistic job possible of shaping that raw material into a product of the highest possible beauty and usefulness? Is not the teacher at least partly to blame for failures in the learning—therefore the teaching—process?

This point of view may grudgingly be accepted by most teachers, but the general practice of testing and assigning grades on a continuum from A to F so that they follow a normal distribution curve (whatever that may mean in terms of the varied backgrounds of young people and modern objectives of instructing them) is simply an anachronism that is both stupid and vicious when it is used in general-education courses.

It is as absurd to set arbitrary standards of accomplishment for all students—the mentally lame, halt, and blind, as well as the alert, brilliant, and seeing—as it would be for a cabinetmaker to insist that each piece of wood in his shop turn out to be the same type of furniture, willy-nilly, and be graded accordingly. If a knotty piece of pine doesn't attain the final beauty and utility of a magnificent piece of primavera, why hold to your standards, artist, grade it down—flunk it!

A bit absurd isn't it?

Good teachers never make this ridiculous mistake. They avoid it partly by recognizing that evaluation is to a large extent a diagnostic device whereby the teaching process can be evaluated and improved. They avoid it by evaluating their students prior to teaching, while they are taught, and at the conclusion of major units. In short, to the best of their ability they determine the raw materials they work with, study the degree to which each youngster appears to be developing according to his promise, and diagnose the teaching process in order to modify it better to achieve the desired results. A prime purpose of evaluation should be diagnosis for the improvement of instruction. Student grades are a bit beside the main point.

Evaluation of Student Growth

It is of course necessary to evaluate student growth. It is necessary for the purpose of diagnosis already explored and it is necessary in order that the learner may determine his own growth and progress. He is, it is patent, a large part of the learning situation.

If evaluation is to be of any worth either to the student or the teacher it must be validly based upon objectives that both the teacher and the learner understand and accept.

The first step in evaluation is therefore the establishment of clear, achievable, and behaviorally stated objectives (see Chapter 7). This step is as necessary for evaluation as it is for all other phases of planning and carrying out sound instruction.

The second step in evaluation is the clearest possible analysis of the "raw material" in terms of the objectives; for, unless the teacher accepts the notion that all his students should be judged against arbitrary standards and tested for the purpose of competitive placing on a distribution curve of some sort, he will recognize that his objectives must be considered as goals toward which his students may variously grow. This second step, which is essentially pre-evaluation, cannot be accomplished by preparing and using a single paper and pencil test. It cannot be done in a single day or week. Sound evaluation is a continuous process in which analysis and diagnosis provide both teacher and students with growing understanding of their abilities, weaknesses, successes, and failures.

The third step, as already indicated, grows out of and is really a part of the second step. It is the study of progress toward objectives. Best made through the fullest cooperation of students and teacher, it utilizes all possible means for the determination of how well the teaching and learning process is achieving the results accepted and desired by both teacher and learners.

EVALUATION INSTRUMENTS AND TECHNIQUES

Reliability and Validity in Evaluation

"Validity" and "reliability" are terms which have already been used. They should be explained in greater detail.

Validity refers to the degree with which an evaluation instrument or technique tests what it is supposed to test. An instrument that provides only blanks where students can insert missing words is not valid for testing their ability to analyze data. An instrument that tests factual recall is not valid for testing how well a student can use facts in functional situations.

Reliability refers to the consistency with which an instrument or technique tests whatever it tests. If a test of one hundred items is broken into two tests and one is given right after the other with precisely the same results, the test is highly reliable. It may not test what the teacher thinks it tests, but it does provide consistent results.

Formal Objective Tests

Formal objective tests tend to be highly reliable. Those that are produced commercially by the better test houses are well constructed and their reliability has

been determined and reported statistically. Any teacher can construct his own formal objective tests. If he constructs enough test items, he can develop almost any degree of reliability in them he chooses. The more the items, the greater the tendency to reliability, simply because sampling defects are reduced. Theoretically, for example, a chemistry test could be constructed that would include items covering every single datum taught in the course. Such a test would be highly reliable compared with a test which included only ten items sampled from the entire course.

The validity of such tests is quite another matter. Note the following item from a formal objective test.

Mark T for true or F for false.
——Electricity travels at the same rate of speed as light.

For what is this item valid? Will it evaluate understandings of principles and their applications to various problems or situations? Will it determine with what facility a student can analyze data or whether he knows the nature of proof? Does it reveal his attitudes or social awareness of the significance of electrical energy and its transmutations into other forms useful in men's lives? Does it give any clue to how well a student can handle specific problems of electrical phenomena?

At best it does one thing. It may validly determine whether the student knows that electricity travels at a different rate of speed than light. It determines nothing more, and the student might get the right answer by guessing.

It is possible to construct or to purchase formal objective tests that test for far more than factual recall with some degree of validity. In the examples that follow, the reader is urged to consider probable validity in terms of various types of objectives, from factual recall to power of critical and independent thinking. Only a single example will generally be given of each type of test item.

True-false items. The true-false test is easy to construct and is therefore more widely used than any other kind. It has its proper uses, no doubt, but they are quite limited. The student is given a chance to choose whether a statement is true or false. For example,

——The molecular weight of Na_3PO_4 is 164.

There are many variations of the true-false item. The "cluster true-false item" provides a partial statement followed by several phrases or clauses, each of which may form a complete true or false statement.

For example,

A transformer

——requires the use of direct current.
——steps both the voltage and current up or down.
——has a primary and at least one secondary coil.
——has little practical usage.

There are several variations of true-false tests that tend to improve the items and to require more thought on the part of the student. Consider, for example, the following "modified true-false item." The directions to the student require that he not only specify whether the statement is true or false but also justify his answer by inserting a statement in the space provided.

> ——The nucleus of an atom has an excess of protons and is therefore negatively charged. (______________________________
>
> ____.)

The statement is, of course, false. But the student is required to indicate why it is false before his answer "false" would be considered adequate.

Matching items. There are various types of matching items. The most commonly used presents two columns of words, clauses, or statements, and the student is required to match them correctly, item by item, by inserting the number or letter of an item in one column in the proper blank provided in front of the correctly corresponding item in the other column. For example,

——Hormone	1. Resistance to disease
——Immunity	2. Something produced by the body which combats injurious effects of foreign substances
——Parasite	3. Chemical substance produced by the body which serves as a regulator or coordinator
——Antibody	4. Type of blood cell that destroys foreign substances in the body
——Phagocyte	5. Organism that lives at the expense of another

Such items are superior to true-false items because of the flexibility of responses that can be required. They may be prepared so that students are required to match causes with effects, problems with solutions, terms with definitions, principles with situations to which the principles apply or are relevant, symbols with their names, parts with their proper units, and so forth.

Recall items. There are various types of recall items. Typically, they require that the student provide a word, clause, sentence, or statement that will complete a clause or that will answer a question. For example,

> Assume that a man is homozygous for black eyes (dominant), and a woman is homozygous for blue eyes (recessive). They have four children. What would be the phenotype and genotype of each child?
>
> ____
>
> ____
>
> ____

Recall items are easy to construct and they can be made to demand considerably

more thought than the true-false item. They are limited, however, in that they basically are what their title implies, items which demand factual recall. In addition, the principle or major idea behind the item is often obscured by the necessity for the student to recall technical terms or to understand technical jargon. The example given is of this type. A student might know what happens in meiotic division in parents who are purebred for the character being considered, but might forget the meaning of such terms as homozygous or phenotype. If the teacher reworked the example so that technical terms were at a minimum, he would be better able to determine what his students knew about the substance of this item on Mendelian inheritance. Separate items should be constructed to determine vocabulary attainment.

Objective Tests of Critical Thinking

There are other types of formal objective test items. There is little profit in sampling them all, for most of them appear in a wide variety of commercially prepared and distributed tests.

The Progressive Education Association Tests. The reader may be interested in studying the unusual and quite excellent modifications of the formal objective tests that were prepared by the Progressive Education Association (which ceased to exist a few years ago). The ones entitled "Nature of Proof" and "Application of Principles" are particularly worth study. An example of each is reproduced below in case the reader cares to construct tests on these general patterns. As the method of response is rather complex, the complete instructions to the students are given prior to an example of each type of test.[1]

THE PROGRESSIVE EDUCATION ASSOCIATION TESTS OF CRITICAL THINKING

Nature of Proof 5.21

Directions to the Student

This is a test of your ability to analyze arguments and to judge the soundness of conclusions drawn from these arguments. Some of the arguments and conclusions are related to social problems, others to science.

Following the underlined conclusion in each problem in the test you will find a number of statements. Some of these statements support the underlined conclusion; some contradict it; and some have no real bearing upon it. After carefully reading the problem, you are to judge these statements in several different ways in the following order:

[1] For further information concerning these tests, how they were constructed, and how the responses are interpreted, see Eugene R. Smith and Ralph W. Tyler, *Appraising and Recording Student Progress* (Progressive Education Association, Committee on the Relation of Schools and Colleges, *Adventure in American Education*, Vol. 3; New York: Harper & Brothers, 1942), pp. 35–76.

A—Select all those statements which *either support or contradict* the underlined conclusion. Blacken the space under *A* opposite the number of each such statement.

B—Now, read over only the statements which you marked under *A*. From these, select all the statements which *support* the underlined conclusion. Blacken the space under *B* opposite the number of each supporting statement.

C—Now, read over only the statements which you marked under *B*. From these, select those statements which you do *not* consider *satisfactorily established by whatever general information you may have, but* which you consider *necessary in the argument* if the underlined conclusion is to be completely justified. Blacken the space under *C* opposite the number of each such statement.

CONCLUSION

Now, according to what seems *most consistent with your analysis* of the argument, decide whether you are inclined to accept, be very uncertain about, or inclined to reject the underlined conclusion. Blacken the space *in the block called "Conclusion"* under:

A—If you are inclined to accept the underlined conclusion.

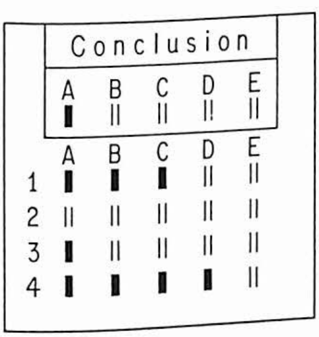
B—If you are very uncertain about the underlined conclusion.

C—If you are inclined to reject the underlined conclusion.

REASONS

Now, read only those statements which you marked under *C*. Of these, mark under *D* those statements which *might cause you to reconsider your decision* about the underlined conclusion, *if more information were made available to you.*

The sample student answer sheet given below shows how one student marked *part* of his answer sheet for Problem I. [Note. Sample Problem I is not included here, since only the method of response is being considered at this point. One of the problems from the test follows.]



Under *A*, this student felt that statements 1, 3, and 4 either supported or contradicted the underlined conclusion. Under *B*, he felt that of the statements 1, 3, and 4, two of them, 1 and 4, supported the underlined conclusion. Under *C*, this student felt that statements 1 and 4 might not be well established but must be included in the argument, if the underlined conclusion was to be justified. He then decided that his analysis pointed toward accepting the underlined conclusion, so he blackened the space under *A in the block called "Conclusion."* Finally, he indicated under *D* that if more information about statement 4 were made available to him at some later time, this might cause him to reconsider his decision about the underlined conclusion.

PROBLEM IX

In a radio broadcast the following story was told: "The people in a little mining town of Pennsylvania get all their water without purification from a clear, swift-running mountain stream. In a cabin on the bank of the stream about a half a mile above the town a worker was very sick with typhoid fever during the first part of December.

During his illness his waste materials were thrown on the snow. About the middle of March the snow melted rapidly and ran into the stream. Approximately two weeks later typhoid fever struck the town. Many of the people became sick and 114 died." The speaker then said that this story showed how the sickness of this man caused widespread illness, and the death of over one hundred people.

STATEMENTS

1. Typhoid fever organisms can survive for at least three months at temperatures near the freezing point.
2. Good doctors should be available when an epidemic hits a small town.
3. Typhoid fever germs are active after being carried for about half a mile in clear, swift-running water.
4. There may have been other sources of contamination by waste materials containing typhoid fever germs along the stream or at some other point in the water supply of the town.
5. The waste materials of a person who has a severe case of typhoid fever contain active typhoid organisms.
6. Typhoid fever is contracted by taking the typhoid organisms into the body by way of the mouth.
7. Only a few people in this town had developed an immunity to typhoid fever.
8. Typhoid organisms are usually killed if subjected to temperatures near the freezing point for a period of several months.
9. Sickness and death usually result in a great economic loss to a small town.
10. The only typhoid organisms with which the people in the town came in contact were in the water supply.
11. Vaccination should be compulsory in communities which have no means of purifying their water supply.
12. The worker's waste materials were the only source of contamination along the stream.
13. There may have been other sources of typhoid fever germs in the town such as milk or food contaminated by some other person.
14. The symptoms of typhoid fever usually appear about two weeks after contact with typhoid germs.

The Application of Principles in Science (Test 1.3a)

PROBLEM I

What happens to the cooking time when an egg is cooked in an open kettle of boiling water on a high mountain?

Directions: Below are three conclusions—A, B, and C. Choose the conclusion which you believe is most consistent with the facts given above and most reasonable in the light of whatever knowledge you may have. After making your decision, turn to the *Answer Sheet*. Under Problem I you will find spaces for five conclusions—A, B, C, D, E. Fill in with a *very heavy black line* the space *under* the letter which corresponds to your conclusion. (Disregard the spaces for Conclusions D and E in this problem.)

CONCLUSIONS

A. It is the same as the cooking time at sea level.
B. It is less than the cooking time at sea level.
C. It is greater than the cooking time at sea level.

Directions: Which of the following statements would you use to explain or to support *your* conclusion?

When you come to a statement which you would use, turn to the *Answer Sheet* and fill in with a *very heavy black line* the space opposite that number and *in the column* which represents your conclusion.

Sample: Problem I

	A	B	C	D	E
	▮	||	||	||	||
	A	B	C	D	E
1	▮	||	||	||	||
	A	B	C	D	E
2	||	||	||	||	||
	A	B	C	D	E
3	▮	||	||	||	||
	A	B	C	D	E
4	||	||	||	||	||

This student chose Conclusion A and reasons 1 and 3 to support his conclusion.

Notice that all of his marks are in Column A because that is the conclusion he checked.

Note: Place marks *only* in that column which represents your conclusion. Do not put marks in any other column.

Reasons

1. Everyone who has studied science knows that the boiling point of water decreases as the altitude increases.
2. An egg will not cook as quickly on a mountain top as at sea level.
3. A reduction in the boiling point accompanies a reduction in the pressure above the water.
4. Decreased air pressure on mountain tops increases the efficiency of fires for cooking purposes.
5. Just as foods cook more slowly at low temperatures, so will eggs cook more slowly on a mountain top where the temperature is low.
6. A reduction in air pressure accompanies an increase in altitude.
7. A solid in solution raises the boiling point of water.
8. Experienced mountain climbers claim that it takes more time to cook foods at high altitudes than at low altitudes.
9. The ordinary way of cooking on mountain tops is to use a pressure cooker.
10. Water boils at the same temperature everywhere.
11. A reduction in the cooking temperature requires an increase in the cooking time, or an increase in cooking temperature requires a reduction in cooking time.
12. The boiling point of the water rises as the pressure above the water becomes less.
13. Water boils at a lower temperature at high altitudes in order to offset differences in cooking time.
14. Changes in altitudes do not influence the boiling point of water.

The comprehensive examinations of the University of Chicago. The University of Chicago has developed an excellent battery of formal objective tests through its Board of Examinations. Although these tests are constructed for the

purposes of evaluating student achievement in college courses in science, they merit careful study by the science teacher who works at the high school or junior college level. The reader is referred to the *Manual of Examination Methods* published by the Examination Board for a valuable discussion of the construction of formal objective items of all sorts. The following examples are taken from the listing of *Sample Questions,* published by the Board of Examinations, University of Chicago. The reader can secure a copy of this bulletin, as well as copies of the comprehensive examinations used in previous years for the natural sciences, physical sciences, and biological sciences, by application to the Board of Examinations, University of Chicago, Chicago, Illinois. The following two examples are given with the statement of objectives to which they refer as listed in *Sample Questions,* April 1948.

Changes in students' ability to apply facts and principles to new problem situations

1. Ability to predict the probable effect of a change in a factor on a biological situation previously at equilibrium
2. Ability to choose, on biological grounds, the best course of action in a problem situation involving health, citizenship, or other human needs
3. Ability to select or identify the most probable cause (s) of an observed change in a biological situation
4. Ability to distinguish effective from ineffective ways of dealing with a problem situation
5. Ability to defend, on biological grounds, choices of correct courses of action in problem situations

(Suggested time for this battery, 10 minutes)

Directions: For each of the following statements, *blacken* answer space.

A—if the statement is consistent with the *Darwinian* conception of evolution, but not with the *Lamarckian* conception of evolution or the hypothesis of *special creation.*
B—if the statement is consistent with both the *Darwinian* and *Lamarckian* evolutionary conceptions, but not with the hypothesis of *special creation.*
C—if the statement is consistent with the *Darwinian* conception and *special creation* hypothesis, but not with the *Lamarckian.*
D—if the statement is consistent with *all three* conceptions.
E—if the statement is inconsistent with the *Darwinian* conception.

46. The wolf and the fox have a common ancestor.
47. Trees growing along the Pacific coast often bend inland away from the wind, whether grown there from seed or planted there as small trees.
48. The descendants of the trees in item 47, which have been grown for many generations in this windy place, if reared in a calm site grow as erect as trees native to that calm site.
49. A breeding experiment is conducted with many generations of rats. Short-haired animals are selectively mated to each other, and only that half of each generation with shorter hair is retained in the experiment. The laboratory, however, is kept at a temperature well below that of the natural habitat of these rats. At the end of the experiment, the average length of hair based on *all* the individuals in the

last generation is very much less than the average hair length based on all individuals in the *first generation.*

50. Throughout the world, the plants and animals characteristic of tropical regions are very different from those of temperate regions.
51. While the Carlsbad caverns are inhabited primarily by blind animals, successive generations of mice reared there in a small laboratory in total darkness have eyesight as good as their normal forbears.
52. In both plant and animal kingdoms, offspring tend to resemble their parents.
53. The serum of a rabbit which has been inoculated with the serum of a pig is agglutinated less strongly by chicken serum than horse serum, still less strongly by shark serum, imperceptibly by earthworm serum. Other similar experiments reveal that, in each case, the serum of a rabbit which has been sensitized to that of a particular animal is more strongly agglutinated by the sera of animals thought to be closely related phylogenetically to the sensitizing animal than by the sera of animals thought to be more distantly related.
54. It is impossible to improve the commercial value of domestic plants and animals by breeding.
55. The birth-rate among residents of upper- and middle-class urban areas is much lower than among slum residents.

Changes in students' ability to apply the scientific method, as exemplified in biology

1. Ability to identify or plan a scientific experiment to test a biological hypothesis, providing adequately for numbers, specificity, and control
2. Ability to distinguish among warranted, unwarranted, or contradicted conclusions drawn from a body of data
3. Ability to distinguish between the *kind* of inference (whether correct or erroneous) which may be drawn from a body of data, and the kind of inference (e.g. teleological or transcendental) which, in a scientific procedure, may not
4. Ability to recognize implied assumptions which are needed to complete a chain of evidence or justify a position
5. Ability to distinguish relevant from irrelevant data in evaluating an hypothesis
6. Ability to identify or formulate the problems involved in a biological situation
7. Ability to identify or formulate hypotheses, and distinguish them from other kinds of statements
8. Ability to recognize when necessary and sufficient data are available to support a conclusion

Scientific Method (Suggested time for this battery, 30 minutes)

Occasionally, sterile female calves are born. Some of these sterile females, known as free-martins, have a distinguished group of characteristics. An investigator was interested in determining the cause of the development of free-martins. He made the following observations. Assume that all possible factors bearing on the development of free-martins are considered here.

1. Single birth female calves, and one-sexed twins (two females) were never free-martins.
2. Single birth male calves, one-sexed twins (two males) and the males born twin to a female calf were regularly normal.
3. Of 126 cases observed, 114 of the female calves born twin to a male calf were free-martins; twelve were normal.

4. The free-martin condition has not been reported in sheep, or in man, both of which occasionally give birth to twins of opposite sexes.
5. When twins, either of the same sex or of opposite sexes, develop in cattle, their embryonic membranes fuse, and usually the blood vessels join, the result being an intermixture of the blood of the two embryos. Such was found to be true in the 114 cases of free-martins.
6. The blood vessels had failed to join in the cases of the 12 normal female calves born twin to male calves.
7. In sheep, the embryonic membranes of twins fuse, but no joining of blood vessels occurs. In man, joining of blood vessels occurs only between identical twins (twins of the same age, and therefore of the same sex).
8. In no instance does fusion of blood vessels occur without fusion of embryonic membranes.

In the left-hand column (nos. 96–108) below is given a series of conclusions which may or may not be warranted. In the right-hand column (nos. 126–138) some of the observations are listed by NUMBER. Each item in the right-hand column refers to the conclusion immediately to the left; e.g. 126 refers to 96, 127 to 97, etc.

Directions:

First: For each CONCLUSION, blacken answer space

A–if the conclusion is warranted
B–if the conclusion goes beyond the data
C–if the conclusion is contradicted

Second: For each WARRANTED OR CONTRADICTED CONCLUSION, *blacken* the one answer space corresponding to the observation or group of observations which *best* justifies the conclusion. Note that some conclusions may be warranted by one observation only, while others may be warranted only on the basis of a number of observations taken together. In every case *blacken* the letter which corresponds to the *minimum* number of observations which are necessary to justify a given conclusion. For each conclusion that GOES BEYOND THE DATA, *blacken* answer space E.

It is understood that every conclusion applies to the species of animals tested under conditions of these observations. Assume that adequate repetitions of the observations have been made.

CONCLUSIONS

96. In cattle, the presence of a male twin to a female is a necessary cause of free-martins.

126. A–1, 3
B–2, 3
C–3, 4
D–3
E–beyond

97. In cattle, the presence of a male twin to a female is a sufficient cause of free-martins.

127. A–5
B–4, 7
C–3, 5, 6
D–4
E–beyond

98. In cattle, the presence of a male twin to a female is the cause of free-martins.

128. A–4
B–3, 5, 6
C–4, 7
D–5
E–beyond

99. In cattle, fusion of the embryonic membranes of male-female twins is a necessary cause of free-martins.	129. A–4, 7, 8 B–3 C–8 D–3, 5, 6, 8 E–beyond
100. Fusion of the embryonic membranes of twins of opposite sexes is a sufficient cause of the free-martin condition.	130. A–8 B–5, 6 C–4, 7 D–3, 8 E–beyond
101. In cattle, fusion of the embryonic membranes of twins of opposite sexes is the cause of free-martins.	131. A–3 B–3, 5, 6 C–4, 7 D–5, 6, 8 E–beyond
102. In cattle twins, when the blood vessels join, a male twin always causes its twin to be sterile.	132. A–2, 5 B–5 C–3, 5, 6 D–2 E–beyond
103. In cattle twins, when the blood vessels join, it is probable that the male twin produces some substance which is carried by the blood and causes the female twin to be sterile.	133. A–3, 5 B–3, 5, 6 C–2, 5, 6 D–4, 7 E–beyond
104. The embryonic testes of the male twin in cattle produce a male hormone which causes the female twin to be sterile.	134. A–3, 5 B–3, 5, 6 C–2, 5, 6 D–4, 7 E–beyond
105. The free-martin condition would occur in man if the blood vessels joined in twins of opposite sexes.	135. A–4, 7 B–4 C–7 D–5, 6, 7 E–beyond
106. Actual joining of the blood vessels must occur for a free-martin to be produced in cattle.	136. A–3, 5, 6 B–2, 5, 6 C–4, 7 D–3, 5, 6, 8 E–beyond
107. Joining of the blood vessels of twins is sufficient to cause one of the pair to be sterile.	137. A–1, 4, 7 B–1, 5 C–2 D–5, 8 E–beyond

108. The free-martin condition never occurs in sheep because the membranes of twins never fuse.

138. A—3, 5, 6
B—4, 7
C—7
D—4
E—beyond

The Illinois Test of Ability to Judge Interpretations of Data. One of the most interesting of the recent formal objective tests designed to test various aspects of critical thinking was developed by the Unit on Evaluation of the Bureau of Research and Service of the College of Education, University of Illinois. This test has two forms. In one form, the student is given a set of data, usually in graphic form, and is asked to respond to a number of specific statements. Each statement is to be answered *in terms of the data given*. The student is to indicate whether each statement is (1) true, (2) probably true, (3) insufficient data to judge truth or falsity, (4) probably false, or (5) false.

The alternate form of the test provides identical data, but instead of expository statements of fact, the student is presented with a running account of a situation in which individuals discuss the data and make declarative statements in a context generally fraught with emotion and valuative judgments. This provides a "real-life" situation comparable to that in which people often must determine the validity of statements and separate facts from opinions and normative judgments. The student is to respond to the numbered statements that appear in the account in the same fashion as indicated in the preceding paragraph. This provides an opportunity to determine the degree to which he uses considered judgment and skill in thinking despite the context of the emotion-fraught situation which is discussed.

The use of the two forms of the test makes it possible to discover to what extent a student is affected by the realistic, emotionally tinged setting in which factual data are presented. This provides an excellent basis for diagnosis with the students, corrective teaching, and the possibility of increasing awareness of demagoguery and misuse of data and thereby increasing critical-mindedness.

One example of each form of the test follows. The reader will note that the data given are precisely the same in each instance.[2]

The chart on page 253 gives the number of deaths in the United States per 100,000 of the population in the age range noted. All deaths counted resulted solely from automobile accidents. Therefore, a point on the graph represents the number of persons out of every 100,000 in the age group who died from automobile accidents in a given year.

Make a decision about each of the numbered statements on the basis of the above information, and indicate your decisions on the answer sheet as follows:

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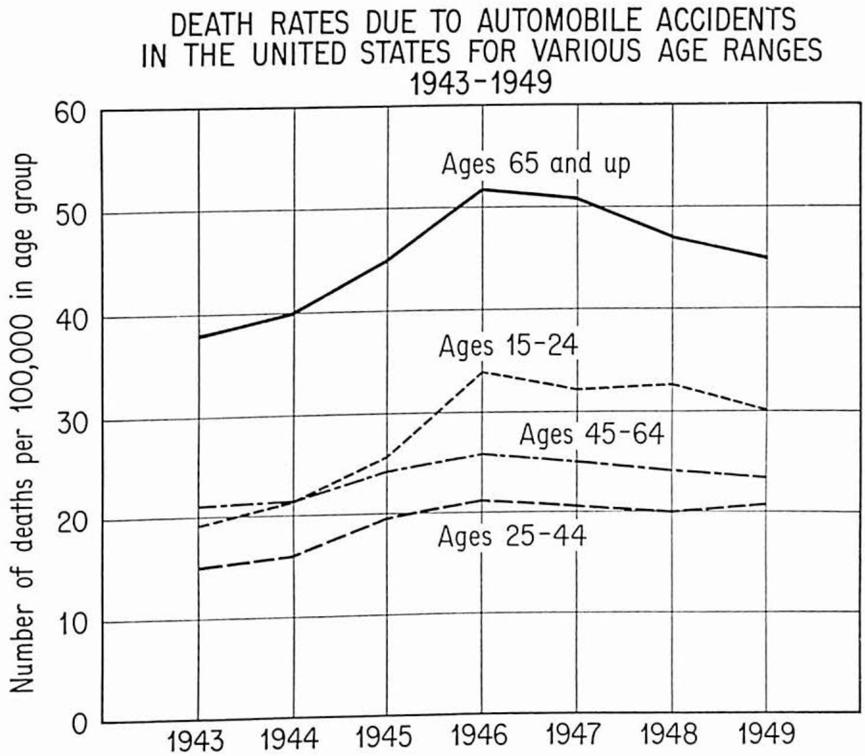
[2] This test item, the one which follows, and the statement of interpretation concerning the test items are taken from *Illinois Test of Ability to Judge Interpretations of Data* (Urbana, Ill.: Unit on Evaluation, Bureau of Research and Service, College of Education, University of Illinois), Forms 2A and 2B. Dr. J. Thomas Hastings, Director.



1 It is *true*
2 It is *probably true*
3 The facts alone are *not sufficient* to indicate whether there is any degree of truth or falsity in the statement
4 It is *probably false*
5 It is *false*

106. In 1949 thirty out of every 100,000 persons in the 15–24 age range were killed by automobile accidents.
107. The accident death rate in 1949 for the age group 15–24 is twice what one finds given the same year for those in middle age.
108. In the short space of only the six months between the end of 1945 and June of 1946 the accident death rate rose from 27 to 30 deaths per 100,000 population.
109. By 1950 the accident death rate in the 15–24 age range will be over 34 deaths per 100,000 population.
110. The accident death rate for the 45–64 age range will be about 21 deaths per 100,000 population in 1950.
111. These data incontrovertibly show that in contrast to the safe and mature older driver the youthful driver is irresponsible and careless.
112. Back in 1942 the accident death rate for the 15–24 age range was below 10 deaths per 100,000 population.
113. These facts show that the best time for changing the 15–24 age range rate was back in 1945 just before the accident death rates took a marked jump upward.
114. The accident death rate for those in the 65 and up age range at its closest point is still about 14 deaths per 100,000 higher than the 15–24 age range rate.

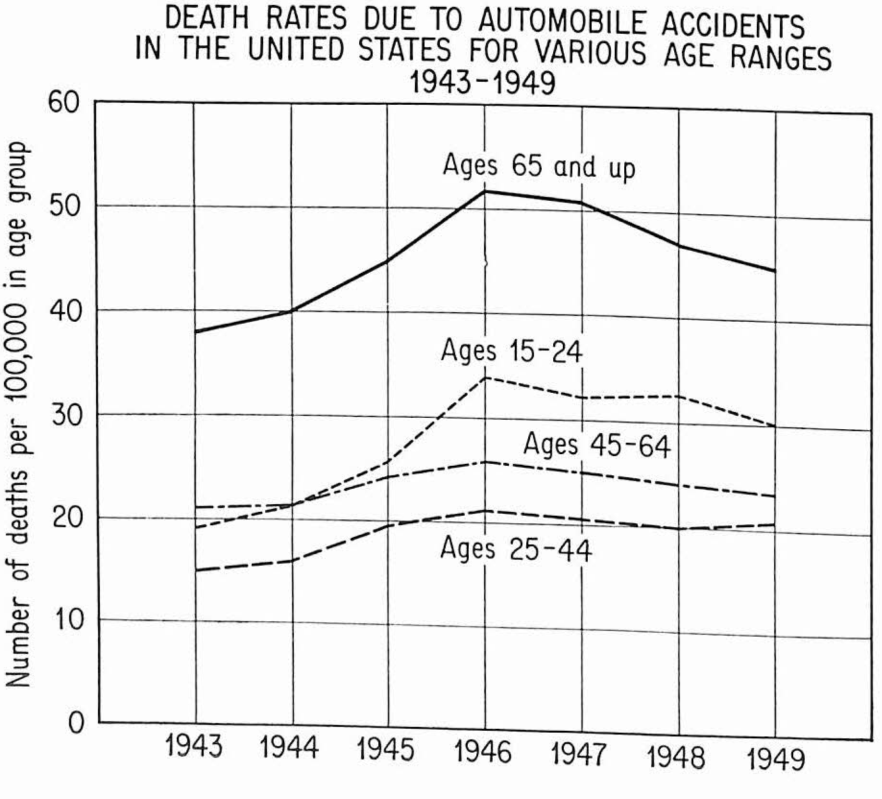
115. In 1943 the accident death rate for the 15–24 age group was below the rates of all except one of the other age groups.
116. By June of 1943 the 15–24 accident death rate rose faster than at any later time.
117. In June of 1946 the 15–24 accident death rate dropped sharply.
118. The data clearly show that the driver-training programs which have recently been started will show up as effective in the future.
119. Part of the reason the accident rate for those age 65 and up is so high is that they all learned to drive when they were adults.
120. If we had the data for 1950, the 65 and up accident death rate would be shown to have turned sharply upward.

The chart below gives the number of deaths in the United States per 100,000 of the population in the age range noted. All deaths counted resulted solely from automobile accidents. Therefore, a point on the graph represents the number of persons out of every 100,000 in the age group who died from automobile accidents in a given year.

Make a decision about each of the numbered statements on the basis of the above information, and indicate your decisions on the answer sheet as follows:

1 It is *true*
2 It is *probably true*
3 The facts alone are *not sufficient* to indicate whether there is any degree of truth or falsity in the statement
4 It is *probably false*
5 It is *false*

No one else in the state thought so, but the Charlottesville basketball team felt that



this year it had a good chance to get to the "Sweet Sixteen," the Illinois State Basketball Tournament. Then quite suddenly several of the key members of the squad were badly injured in a completely unnecessary automobile accident. The team's chances fell to zero! The townsfolk were stunned! "Those crazy kids!" they exclaimed. "Well, it's just too bad! We won't have another team like that for years." But while the townsfolk felt cheated by fate, the parents of the high school students took the accident to heart. In addition, their collision insurance rates had just been doubled. That hit where it hurt—in the pocketbook. "Too many kids on the road," the insurance agent had said.

As a result, the P.T.A. set up a committee to consider the problem. The committee, after due consideration, recommended a mass "strike" by the parents as the best way to solve the problem both from a safety and an economic standpoint. That is, they recommended depriving all the students in the school of the right to drive cars. Further, they pointed out there would be none of that "But, Mom, Billy's folks let him!" pressure. It sounded like it might have possibilities. Mrs. Teagarden, the committee chairman, presented the proposal at a recent meeting, supporting her points with some data published by the National Safety Council:

"I know that this is a question of vital interest to us all. The way the youngsters drive around this town like madmen has us all concerned. I think our committee has the answer. It may seem like a severe one; but after you have seen the facts, I am sure you will agree that the problem is so serious that it calls for a severe answer. Look at the facts. They show that in the younger age ranges ages 15–24 on the chart, when many of at least the younger of that range should not be driving cars, (106) in 1949 thirty out of every 100,000 persons were killed by automobile accidents. (107) This accident death rate is twice what one finds given for those in middle age. By middle age the drivers are more mature and responsible. But, what is more alarming (108) is that in the short space of only six months, from the end of 1945 to June of 1946, the accident death rate for those in the 15–24 age range rose from 27 to 30 deaths per 100,000 population. Further, the accident death rate rise during 1946, 1947, and 1948 was so rapid that (109) by 1950 the accident death rate in the 15–24 age range will be over 34 deaths per 100,000 population. In contrast to this, in the 45–64 age range a *decline* in accident death rates continued through the same period of years so that (110) in 1950 the accident death rate in that age range will be about 21 deaths per 100,000. (111) These data incontrovertibly show that in contrast to the safe and mature older driver the youthful driver is irresponsible and careless.

"(112) Ten years ago, back in 1942 when some of us were in the 15–24 age range, the accident death rate was below 10 deaths per 100,000. Today it is three times that. The youth of today have been growing more irresponsible all the time. We must protect them from themselves. We must protect the other members of our community. Our committee recommends that the children of the community not be allowed to drive cars, trucks, or any other heavy murderous vehicle until they have graduated from high school. (113) The facts show that the best time for action on the problem was back in 1945, just before the accident death rates took a marked jump upward. It is not now too late, however, to consider our recommendation seriously. I am sure you will agree that it is a fair, a reasonable, and a sure solution."

Bill Briggs, a young, likable sort of fellow, was the basketball coach of the high school. As part of his teaching load he was responsible for the safe driver-training program. The recommendations of the committee came as a shock to him. Not only had he lost his chance at the basketball championship with that one accident but now the whole driver-training program would be wiped out. So Bill just had to answer Mrs. Teagarden. He found it rather hard to get started:

"Mrs. Teagarden, members of the Committee, and members of the P.T.A." There was an uneasy pause as he stopped to collect his thoughts. "You all know who I am and what my responsibilities are here in the school. It may surprise some of you, therefore, that I feel I must oppose Mrs. Teagarden's proposal. Yes, I have lost the chance at a championship which means more to me than perhaps to anybody else in town except the team members themselves. Yet, my additional responsibility as driver-training instructor compels me to ask you to take a second look at the facts. You say the older drivers are better? Why does it make any more sense to deprive the high school student the right to drive a car than it does the very responsible and very mature oldster in the age range 65 and up? (114) Their accident rate at its closest point is still about 14 deaths per 100,000 higher than the 15–24 age range rate.

"But, more important, it's when we are young that we form our habits. These youngsters are potentially better drivers than are we adults. Their reflexes are quicker. They are mostly in better health. Being young, they can be easily trained. It is this later aspect, the abandonment of training and of the practice of that training, that I see as the most serious result of this committee's proposal.

"The chart shows the effects of the driver-training program. Back in the early 1940's, when the programs were going in full force, (115) note in 1943, for instance, the accident death rate for the 15–24 age group was below the rates of all except one of the other age groups. Then with the war came the shortage of cars and gasoline and the drafting of driver-training instructors into the Army. School after school found itself forced to abandon its driver-training program. (116) Accordingly, by June of 1943 the 15–24 accident death rate rose faster than at any later time. When the war ended in 1945, schools reinitiated their training programs; and, as would be expected, (117) in June of 1946 the 15–24 accident death rate dropped sharply. It has been dropping ever since. But remember that many who were not trained during the 1944–46 period will still be in the 15–24 age range even beyond 1949. (118) The data clearly show, however, that if we work hard, our driver-training programs will again show up as effective.

"One additional point—there are many students whose families do not have cars. Their one chance to learn to drive is while they are in school. If they can afford a car later, they would have to learn as adults. It is too late then! Look again at the accident rate for those 65 and up. (119) Part of the reason their accident death rate is so high is that they all had to learn to drive as adults. And as motor cars become more powerful and speedy, their accident rate will rise. (120) If we had the data for 1950, the 65 and up accident death rate would be shown to have turned sharply upward. The time to learn to drive is while you are young.

"I hope that when you have considered all the facts, you will reject the present recommendation and seek to find a better way to solve this problem over which we are all so deeply concerned. Thank you."

The following is a statement written by J. Thomas Hastings, Director of the Unit on Evaluation, and others who prepared the test. It accompanied the tests at the time they were used experimentally in the Illinois Statewide High School Testing Program and will help the reader to appraise the test and its uses in diagnosis and teaching.

Interpretation of the Test Scores

You will note that you have been given two sets of scores, each set like the ones described below. The first four scores indicate the student's ability to operate with

statements which are isolated one from the other, with no sequence between them, nor carrying any train of thought. The second four scores are indicative of the student's ability to judge when the statements are presented in context—not as separate isolated statements. In addition to the contextual setting, the statements are built into pro and con arguments about an emotion-arousing topic. The difference between comparable scores, e.g., the two total scores, the two values scores, etc., on the two parts of the test, indicate the extent and manner in which the individual responds to the emotion-arousing context situation. In general, we may expect the second set of scores to be somewhat lower since most people are influenced by their feelings and biases to the extent that their judgment is impaired. Since in real situations arguments for persuasion appear in context, it is probably not desirable that the student's judgment should be impaired seriously by context. Therefore, you will wish to give special attention to those whose scores dropped markedly on the second part of the test.

The test is so constructed that a number of different scores may be obtained. Because we have not sufficiently established the reliability and validity of some of these scores, we are reporting to you only those which the very first studies of the test indicate with some certainty can be validly interpreted. These scores are as follows:

1. Reading Points. If the student is to be able to correctly judge interpretations of the data, he must first be able to read the graph, chart, or table in which the data are presented. The reading points score is an indication of his ability to do this. Each of the statements classified as a reading point is a restatement of the numerical or geographical data in verbal form. All of the data necessary to determine the truth or falsity of the statement is included in the chart, graph, or table given the student. To the extent that a person does poorly on the reading points score, his technical skills score will be lowered. That is, since the technical skills score also requires that he be able to read the data, as well as to think about it, errors in reading, even when accompanied by correct thinking, will show up as a lower technical skills score.

2. Values Score. The values score is an indication of the extent to which the student is able to recognize the statements which require opinions, values, definitions, and assumptions which the data alone do not give. The bulk of the statements in this category are statements involving value judgments. In these statements the author may have jumped to a conclusion, such as "These data indicate that these conditions must be changed." Such a statement not only assumes that the conditions are bad ones—a value judgment—but also that these data are sufficiently representative to justify the conclusion that the condition exists and therefore does need changing. Both of these types of thinking go considerably beyond the data given. This is exactly the kind of thinking most political speakers use in trying to convince one they have the right answer! The student whose value score is low is probably susceptible to persuasion by this kind of argument.

   An additional behavior included in this score is the ability to recognize statements attributing a cause to the person collecting the data, e.g., "These data were collected to show that government spending must be cut." This statement might be true in actual fact; but since the data are not sufficient to show this, the statement would have to be so marked.

   A third kind of statement, the recognition of which is included in this value score, is one which attempts to explain the data or present a rationale for it, e.g., the reason that women live longer than men is that in general they do less physical work.

We do not have sub-scores on the student's ability to recognize these various types of items in the "value category." We are not sure at the present time that such scores would be sufficiently reliable. This is one of the things we hope to investigate from the trial run.

3. Technical Skills. The technical skills items measure the extent to which the individual is able to recognize statements which, while not specified precisely by the data, may nevertheless be safely inferred from them. Three different kinds of statements in this area have been included:

   (1) Interpolation. An important aspect of a chart, graph, or table which represents an over-all picture of a situation is that it rarely gives sufficient detail to allow one to examine each minute facet. The data are usually collected at specific times or for specific miles, etc., and not for points in between these. Although we can, therefore, predict the general characteristics of a specified situation by noting the trend portrayed by the data, we cannot unqualifiably state that they would apply to the specified situation. Such statements would, therefore, be judged as probably true or probably false. Specifically, interpolation items require the student to judge data at a point between those for which precise data are given him. To be adjudged correct, he must indicate the probable truth or falsity of the statement (e.g., the data are given in five-year intervals from 1910 to 1950, and the student is asked about 1942).

   (2) Extrapolation. Items testing extrapolation give an index of the student's ability to correctly extend a trend shown in the data beyond the last date for which data are given. Like the interpolation items, such a projection is never a certainty since conditions might change. The assumption of constant conditions is implicit in an extrapolation statement; and we cannot, therefore, be sure that the situation was such or will be such that the statement would be true or false. But by projecting the trend one is able to judge the probable truth or probable falsity of the statement.

   (3) Sampling. The sampling items give an index of the student's ability to judge the truth or falsity of assertions about a situation where the data given bear only on the situation in terms of a large context. For instance, one statement is "Florida, which has one of the largest populations of the states in the South Atlantic region, had a greater physician-population ratio than nurse-population ratio in 1920." The data are given only for the South Atlantic region. While such a statement cannot be judged definitely true or false (Florida might happen to deviate from the general trend of the states in the South Atlantic region) because Florida is one of the largest of the South Atlantic states, it is unlikely that it will deviate from the general trend of these states. Such statements should, therefore, be judged probably true or probably false.

4. Total Score. The total score gives an index of the student's over-all ability to judge interpretations of data. Except as one compares the total on the first half of the test with that on the second, this score is somewhat less useful than the sub-scores, which can be used for diagnostic purposes. Assuming that the reading points score is sufficiently high to show that the student is able to handle the data, then the difference between the total scores on the two halves of the test is perhaps your best index of the extent to which the student was influenced by his biases and emotions.

What Is a Satisfactory Score?

At the present time we have not given the test to a sufficient number of schools to be able to indicate what level of achievement constitutes a relatively high or a relatively low score. The results are probably best used by looking at the standings of the students in the school relative to one another. The following highest possible scores may also allow you to judge the extent of accuracy shown:

	Part I	Part II
Reading Points	21	21
Value Statements	20	20
Technical Skills	34	33
	—	—
Total	75	74

How Should I Remedy Low Achievement?

Low scores on the first part of the test are perhaps easier to correct than low scores on the second. All of the skills measured by this test are quite teachable and are usually found in the usual school curriculum. For instance:

1. Reading Points. The reading points score can be raised by giving the student practice in reading bar graphs, line graphs, pictographs, and tables. This is normally a part of the mathematics curriculum but also perhaps should be stressed in English (debate, composition, etc.) and social studies.
2. Technical Skills. The skill of interpolation is one which is also normally included in the mathematics curriculum at that point where the students begin to handle tables, e.g., tables of trigonometric functions, logarithms, etc. The skill of extrapolation is a simple and logical step beyond that of interpolation. It may be part of the mathematics or social science program. It is frequently used in the social sciences to predict phenomena. It is a skill which can be quickly learned. The recognition of what constitutes a reasonable "sampling" statement is actually based upon learning how to recognize logical inferences. It occurs in almost every subject matter field. Learning to recognize a reasonable sampling statement is just like learning the necessary limitations on any generalization or reference.
3. Values. The recognition of the distinction between values statements and statements of facts is a skill which, while recognized as extremely important, is rarely directly taught in the high school curriculum. Normally it is something which is incidental to other learning. It probably frequently occurs in civics classes or similar groups where there are discussions of social issues.

By attending to those aspects of the curriculum which are noted above, changes in the student's ability to *be able* to handle data can be brought about. Changes in his thinking processes so that he carries these abilities over into actually *doing* this kind of thinking with reference to the problems around him is more difficult. As you are no doubt aware, we have much to learn about the ways in which emotional learnings are brought about; and we have only some clues as to how to train students so that their thinking is more logical and indicative of good judgment rather than ruled by their biases and emotions. It was, in fact, our hope that out of the preparation of a test such as this we might be in a better position to experiment with and evaluate the various methods of training in this area which have been proposed.

One of the methods which has been used rather successfully with respect to emotional learnings grows out of non-directive therapy. Most people do not really realize the

extent to which their thinking is biased; and when confronted with evidence of the fact that it is, the self-insight resulting from this knowledge and the evidence as to the manner in which it was thus biased are sufficient to cause them to desire to change. Once the desire to change has been awakened, practice in the skill is the essential. Group discussions, debates, and mock legislative bodies are good ways of giving this practice. Students frequently find this fun.

The Max test of interpretation of data in chemistry. The final example we present of formal objective tests designed to assess aspects of critical thinking is from an instrument developed and tested through valid research techniques by Herbert Max.[3] This instrument intentionally combines interpretation of data items with content data from the field of chemistry. It is a good example of the few available tests which provide for each field of science an instrument that assesses the student's ability to understand data and to handle data reflectively.

A TEST TO MEASURE ABILITY TO JUDGE INTERPRETATIONS OF DATA

General Directions

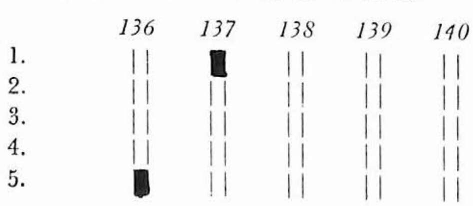
This is an experimental test to measure how well you can judge the truth or falsity of statements when you must base your decision upon a given set of facts or data. All of the data and all of the statements you will be given are related in some way to chemistry. The facts and the data given to you are accurate, but the statements may or may not be. Your task is to read each statement carefully and then, on the basis of the facts and data given to you, decide which of the following answers most accurately describes or fits the statement:

1 The statement is *true*
2 The statement is *probably true*
3 The facts alone are *not sufficient* to indicate whether there is any degree of truth or falsity in the statement
4 The statement is *probably false*
5 The statement is *false*

Always be certain that the number of the statement is the same as the number you are marking on the answer sheet.

Mark only one answer for each statement.

Be sure that you make a heavy, black, distinct mark between the parallel lines when you mark the answer sheet. In the following illustration the student believed item 136 to be false and item 137 to be true.



if you judge the statement *true*
if you judge the statement *probably true*
if you judge the facts *not sufficient*
if you judge the statement *probably false*
if you judge the statement *false*

[3] "The Development of an Instrument to Measure an Aspect of Critical Thinking in the Area of High School Chemistry" (Doctoral dissertation, University of Illinois, 1954).

PROBLEM I

Solubility (in grams) of Gas in 100 grams of Water (Pressure 760 mm.)

Gas	*0 degrees C.*	*10*	*20*	*40*	*60*	*80*	*100 degrees C.*
Carbon Dioxide	0.335	0.232	0.169	0.126	0.058	0.0000	0.0000
Hydrogen	0.00019	0.00017	0.00016	0.00015	0.00012	0.00008	0.0000
Hydrogen Sulfide	0.707	0.511	0.385	0.236	0.148	0.076	0.0000
Nitrogen	0.00294	0.00231	0.0019	0.0014	0.0011	0.00066	0.0000
Oxygen	0.00693	0.0054	0.00434	0.0036	0.00227	0.0014	0.0000
Sulfur Dioxide	22.83	16.21	11.28	5.41	0.0000	0.0000	0.0000

Solubility (in grams) of Solids in 100 grams of Water

Solid	*0 degrees C.*	*10*	*20*	*40*	*60*	*80*	*100 degrees C.*
Barium Chloride	31.6	33.3	35.7	40.7	48.4	52.4	58.8
Calcium Hydroxide	0.185	0.176	0.165	0.141	0.116	0.094	0.077
Calcium Sulfate	0.176	0.193	0.202	0.2095	0.2047	0.1950	0.1619
Cerium Sulfate	20.0	11.0	8.0	2.0	1.0	1.0	1.0
Lead Nitrate	38.8	48.3	56.6	75.0	95.0	115.0	138.8
Potassium Chlorate	3.8	5.0	7.4	14.0	24.5	38.5	57.0
Potassium Dichromate	5.0	8.5	13.1	29.2	50.5	73.0	102.0
Potassium Nitrate	13.3	20.9	31.6	63.9	110.	169.0	246.0
Silver Sulfate	0.57	0.69	0.79	0.97	1.14	1.28	1.39
Sodium Chloride	35.7	35.8	36.0	36.6	37.5	38.4	39.8

The table above is divided into two parts. The upper part pertains to gases, the lower to solids. The pressure is not given for solids because it is not a factor in the solubility of solids. The term *solubility* as used above means the weight of the substance which will dissolve in 100 grams of water at a given temperature. The weights are given in grams.

A substance is soluble in water when the molecules of that substance scatter uniformly throughout the water. Thus sugar will dissolve in water because when sugar is placed in water, the particles of sugar gradually become smaller and eventually disappear from sight by being reduced to molecular size and being scattered throughout the water.

For the purposes of this test we may say that if more than 10 grams of a substance dissolve in 100 grams of water at a certain temperature, the substance is very soluble.

When the amount of a substance dissolving at a certain temperature is a fraction of a gram we may say that the substance is quite or very insoluble.

The statements which follow should be answered and interpreted on the basis of the data given above and only on that basis. Knowledge and information which you may know, but which is not in the data above should not be used in answering the statements. Assume that any reference to solubility below refers to solubility in water. The data for only six gases are given above. There are many other gases known to chemists. Likewise there are many other solids known besides those listed in the table above.

11. Gases are more soluble at low temperatures than at high temperatures.
12. Solids are more soluble at high temperatures than at low temperatures.
13. If the temperature remains the same, stirring makes solids go into solution more rapidly.
14. Potassium dichromate is more soluble at 90 degrees than at 20 degrees.
15. The solubility of sodium chloride at 70 degrees is 38.0 grams in 100 grams of water.
16. Potassium compounds are quite soluble at 80 degrees.
17. It is easier to dissolve 25 grams of lead nitrate than 25 grams of sodium chloride in 100 grams of water at 80 degrees.
18. All nitrates are quite soluble.
19. Sulfates are more soluble at low temperatures than at high temperatures.
20. Potassium chlorate will go into solution more rapidly than potassium dichromate at 60 degrees.
21. At a pressure of 1520 mm. and a temperature of 20 degrees, 0.00032 grams of hydrogen will dissolve in 100 grams of water.
22. Sulfur dioxide will not dissolve in water at 90 degrees and a pressure of 760 mm.
23. At least thirty grams of potassium chlorate will dissolve in 100 grams of water at a temperature of 90 degrees.
24. Barium compounds are more soluble than sodium compounds at 80 degrees.
25. At no temperature is the solubility of a calcium compound greater than 0.2095 grams in 100 grams of water.
26. Carbon dioxide will not dissolve in water at 90 degrees at a pressure of 760 mm.
27. Large pieces of solids go into solution more slowly than small pieces.
28. Gases are not soluble in water at 90 degrees and a pressure of 760 mm.
29. The solubility of hydrogen at 60 degrees and 760 mm. pressure is 0.00012 grams in 100 grams of water.
30. At a pressure of 760 mm. and at temperatures where both gases are soluble in water, oxygen is always more soluble than hydrogen.
31. Potassium compounds are more soluble than sodium compounds at 100 degrees.
32. Ten grams of potassium nitrate will dissolve faster in 100 grams of water at 40 degrees than 10 grams of potassium chlorate.

Essay-Type Tests

The great advantage of essay-type tests over formal objective tests is that essay tests require that students consider a problem, situation, or question and formulate their thoughts and present their thinking as cogently as they can. It provides the teacher with an opportunity to observe how capably a student can organize his thinking and communicate his analysis to others. Life does not consist of filling in blanks to prepared statements. The essay test provides a more life-like situation for the purposes of evaluation and diagnosis.

The great disadvantage of the essay test rests on the fact that there are no highly objective means of scoring it. Many studies have been made which show that well-trained and competent teachers may score the same essay paper quite differently. The scores given a single paper by competent teachers have sometimes ranged from A to D. The essay test suffers from low reliability and the fact that there are no *objective* bases for evaluating.

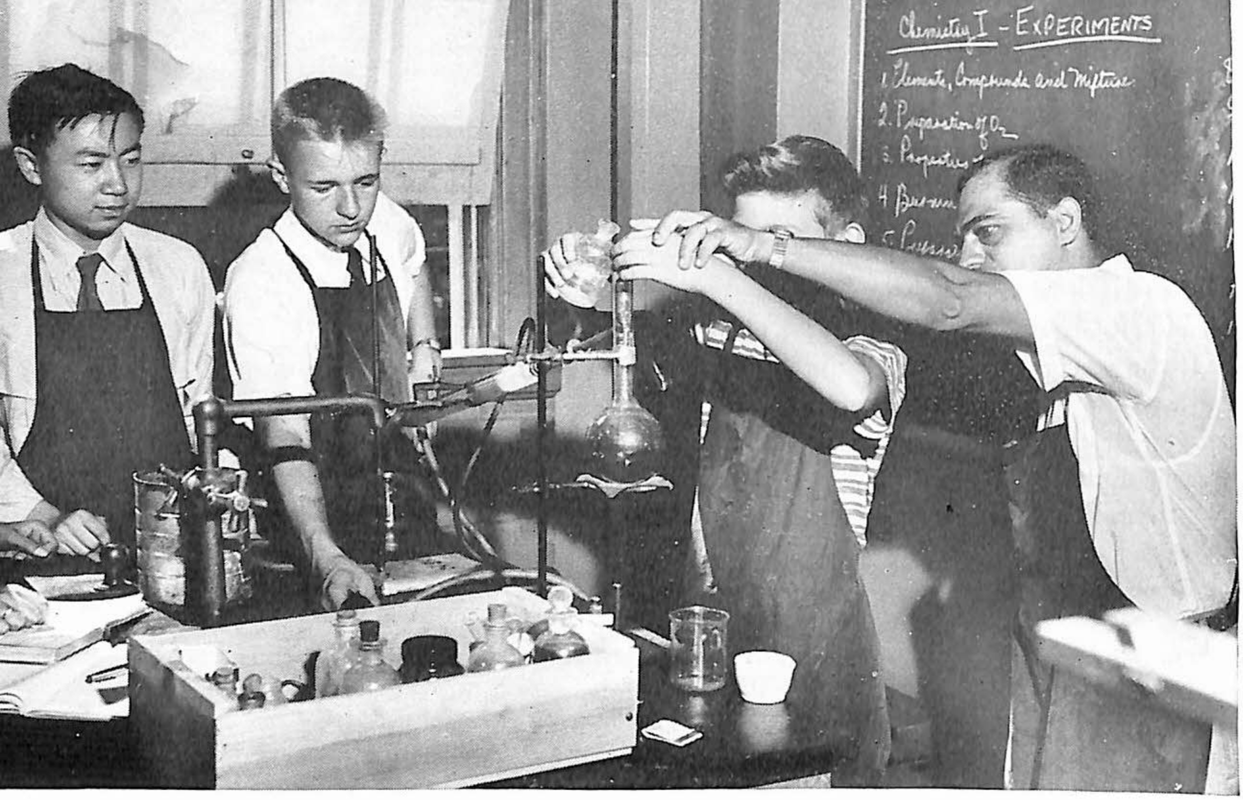
If the teacher were not required to report letter grades, the essay test would be used more widely, as it deserves to be; for from an essay test a teacher can analyze a student's weaknesses and growth more accurately than he can from formal objective tests (if, indeed, he is interested in growth toward the major objectives which have previously been discussed). But it must be emphasized that essay tests always suffer from subjectivity, provide for less adequate sampling of knowledge because of the time required for answering, and allow an opportunity for verbally competent students to bluff.

There are several types of essay tests. Essay-test items may be prepared which require but short and specific answers; for example,

> In the space below indicate the type of lens used to correct myopia (nearsightedness.) Explain *how* such a lens corrects the condition. Use whatever diagrams you need in clarifying your discussion.

Such an item can be scored with a fair degree of objectivity. It can be made even more objective by specifying more detail in the statement of what is required of the student. It might, for example, require the student to show how light refracts in the myopic eye when an object is viewed close at hand, when an object is viewed from a distance, and when the distant object is viewed through a corrective lens.

Quite often an essay test is simply a form of written report. It may be written within the time of a class period with or without the use of reference books or notes, or it may be assigned as the subject of a report. The problem approach to science teaching makes heavy use of such "essay tests" or reports. In the problem approach, the report comes less from an "assignment" imposed upon the student by the teacher than from the student's agreement to accept responsibility for investigating and communicating to the rest of the class a phase of the problem under group analysis. These reports are not essay tests in the conventional use of the term, for the teacher does not assign specific items to be included. But they do share the advantages of the essay-type test in that the student is responsible for formulating his problem, investigating it, and expressing himself so clearly that others will profit from his investigation. It is quite clear that such a responsibility bears the promise of significant growth on the part of the student. It is also clear that a student will require considerable help from the teacher, particularly for his first reports, in order to learn how to prepare his reports effectively. If evaluation is used for determining student growth toward



Each class period, every laboratory hour will provide opportunities for informal evaluation and diagnosis. (Official photograph, Board of Education, City of New York)

clearly seen objectives and for diagnosing instruction, both short-answer essay tests and the longer report type of essays will be found exceedingly valuable.

If short-answer essay tests are given, the various items prepared by the teacher will be specific enough to allow for considerable objectivity in scoring. But the scoring is, of course, the point at which objectivity tends to break down. The following four points will be useful to the teacher in increasing the validity of his scoring procedures. They are taken from *Measuring Educational Achievement* by Micheels and Karnes.[4]

a. Write out the answer expected for each item. Include every point that is to be accepted. Only in rare instances will it be impractical to do this.
b. Score one essay item on all test papers before proceeding to the next.
c. Give value to an item by allowing one point for each point covered in the answer.
d. Conceal the students' names on the test papers, or in some manner make sure their identity is not revealed as the item is being scored.

[4] William J. Micheels and M. Ray Karnes, *Measuring Educational Achievement* (New York: McGraw-Hill Book Company, Inc., 1950), p. 270.

TEACHER OBSERVATION AND GROUP EVALUATION

Evaluation should not be confined to paper and pencil tests or to written reports. Although these are far more objective than subjective judgments based upon observation, critical and continuous observation of the students at work will provide information beyond the scope of tests.

Let us assume that we are interested in such things as cooperativeness, effective speech, sound and constructive participation in group activities, procedural skills, and high standards of general workmanship in tackling problems and investigating them. Standardized tests will provide us an objective basis upon which to judge the growth of our students in factual knowledge and certain types of understandings. The better tests of critical thinking will give us some information regarding aspects of this important skill. There are even effective tests designed to determine the facility with which a student can use the laboratory. But there is no way in which the results of these separate tests can be added together to give us a picture of the students' behavior as an entity. Here is where observation becomes important. The teacher is in a position—particularly in a group-planned, functional program—to observe his students over a long period of time. He can observe how they carry out their laboratory responsibilities, how they accept responsibility and discharge it, how well they utilize reference materials, how effectively they communicate with others, and so forth. If these judgments, admittedly subjective, are considered along with the more objective results of a formal testing program, the teacher will have a sound basis on which to judge student growth. He will also have a basis upon which to judge defects and strengths in his teaching procedure.

Self-evaluation is important, but students rarely have an opportunity to develop skill in it. Each student should be brought as speedily as possible to recognize that *he* is the learner, *his* is the responsibility for his own education, and *he alone* will ultimately determine the degree to which the opportunities he has are realized. Most students go through high school and most of college with a quite passive attitude toward their own education. With lesser or greater degrees of docility or resistance they say, in effect, "Teach me if you can."

This attitude is not the students' fault. We have taught them that attitude by telling them what they must learn, forcing them to follow along the educational path we decide is good for them, and testing and grading them on the basis of arbitrary (and often quite unrealistic) standards that have little to do with their individual powers of attainment or their own conceptions of their needs and goals.

The only method of destroying this passivity and making the learner a positive participant in the learning process is to share with him the total responsibility for his own education. This requires that we challenge him to assess his own strengths and weaknesses, join us in identifying learnings that are worth serious

and sustained effort, and cooperate fully with us in evaluating his progress toward these goals he has helped to set.

Group evaluation is important in this process of self-evaluation. If the teacher alone judges what objectives are sound, makes up the tests or secures tests without reference to the students' opinions of what is valid in terms of agreed-upon objectives, he is short-circuiting the student's growth toward self-responsibility and positive identification in the learning process. After all, if one has helped to determine goals and procedures one has a right to assist in the task of determining how well the goals have been reached by the procedures agreed upon.

Group evaluation consists of encouraging the student group to assist in the setting of goals, in cooperative delineation of procedures, and in deciding the means by which the group and the individuals of which it is composed are to be judged. Students can help in making up tests. They can agree upon techniques and standards of evaluating oral presentations and group discussions. They can decide upon standards and means of evaluating every aspect of the science program, from individual laboratory work to contributions to the group process of problem identification. Group evaluation tends to be far more strict than evaluation by the teacher alone. Its standards tend to be higher, but they vary with the group's perception of student strengths and weaknesses. Group censure of the individual who does not contribute that which the group believes him capable of contributing is a far more penetrating goad to better work than any the teacher can provide. The individual student wants acceptance by the group. He needs it badly. If the *group* has decided on the rules of the game and the standards by which each individual must play, the individual student will not long carry the psychological burden of group censure without trying hard to do something about it.

The primary task of the teacher is this process of self-evaluation and group evaluation is to make certain that the students do become a group rather than a collection of individuals and small groups. It is for the teacher to make certain that this group-mindedness is concerned with important goals and substantial education and that the group is not led by a few students whose search for acceptance has made them buffoons. This task is quite difficult if the teacher places himself in the position of arbitrary authority and opposes the clown or his genus with strict authoritarianism or sarcasm, which many teachers are driven to, despite themselves, if they attempt to maintain an authoritarian classroom. The task is quite easy if the class has learned that their teacher is genuinely interested in them, knows his science and how to teach it, and takes them fully into his confidence as he helps them learn things that are really important.

A second important task of the teacher who wants to engage the students in sound self-evaluation and group evaluation is to help them in the technical aspects of the work. He will need to show his students how constructive criticism can be given—and taken. He will need to show them how to analyze sound oral

or written presentations and to distinguish these from sloppy work. He will need to supervise the construction of all tests made by students, and he will ordinarily find it necessary to spend considerable time polishing and refining any instrument prepared by student committees for administration to the entire group.

But, if the teacher and his students have worked cooperatively and under standards that are high but realistic because they have been set by the group, he will find that his students tend to look behind their scores to determine what their weaknesses were. They become far less grade conscious and far more education conscious. They work hard on judging themselves and in helping to prepare means for the judgment, because they are genuinely interested in what they are learning and want bench marks by which to determine their growth. Such evaluation has all the advantages of competitive work, but it has the added high advantage that each student is competing essentially with himself—he is studying to learn, not to get higher grades than his fellow students.

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ILLUSTRATIVE PROCEDURES AND PRACTICES

IV

Chapter 6 distinguished between science instruction for general-education purposes and that designed for rigorous study of an organized discipline. The more rigorous program was proposed for such courses as chemistry, physics, and advanced biology to be offered for those students whose aptitudes and interests would make the program meaningful and profitable. The general-education offerings were proposed for *all* high school students.

Chapter 6 further suggested that general education might be developed around problems or topics of widespread personal or social value. When this is done, the boundaries between the various sciences and between the sciences and other disciplines are often crossed to permit a more meaningful and comprehensive analysis of basic problems. This is because, by their very nature, basic problems are interdisciplinary.

This section of the book presents several procedures and practices which illustrate the problem approach to general education in action. It also shows how teachers have modified their practice better to meet the needs of the gifted student. Chapter 11 is an example of the interdisciplinary approach to the problem of racism. Chapter 12 describes how a teacher taught a major unit on atomic energy in a core class. Chapter 13 describes how a biology teacher taught a mental health unit. Chapter 14 shows how two different science teachers attempted to meet the needs of gifted students.

Each of these chapters illustrates certain phases of the theories and practices described in earlier sections of the book.

11

COMBATING PREJUDICE THROUGH SCIENCE TEACHING

"Racism," the belief that human races have distinctive and inborn differences in personality—usually accompanied by the notion that one's own racial, ethnic, religious, or cultural group is superior to others—is an important problem amenable in part to scientific analysis and treatment. Contributions to the problem may be made from such fields as genetics, biochemistry, anatomy, anthropology, psychology, and sociology. But, when these areas are kept separate, their contributions to the problem of racism are thereby limited. It is doubtful whether a student studying these contributions separately is in a position to integrate the separate learnings in such a way as to modify his behavior.

The interdisciplinary approach to general education about such problems as racism brings together those things that belong together regardless of their origins in separate research fields. The following material illustrates the interdisciplinary approach. Originally prepared by the author for the National Science Teachers Association and first published by that organization in 1950, this material has had wide distribution and use by science teachers. It is reproduced with the permission of the National Science Teachers Association.

Whether the following material is appropriate for use in a science class or whether it should be taught in a core class or cooperatively by science, social-

The interdisciplinary approach to the study of racism permits the teacher to use such fields as genetics, biochemistry, anatomy, anthropology, psychology, and sociology as they variously contribute to a sound analysis of the problem. (Courtesy of Cleveland Public Schools)

studies, and English teachers is a matter for each teacher to decide for himself. The material has been used for several years in each of these ways. Its most common use, however, has been as resource material for teachers of general-science and biology classes.

Because reference materials may often be inaccessible, the activities suggested in the following include sufficient information for the teacher to enable him to carry them out even though his background in anthropology and genetics and his experience in teaching intercultural relations may be limited. It is stressed, however, that the following material is essentially an outline. Sound teaching would require that the teacher study intensively the basic data which is often only alluded to in this chapter.

The suggestions are grouped under five major headings.

1. Classification of man
2. The origin of races
3. Physical differences and similarities between groups of people
4. The genetic and cultural bases of personality
5. The effect of the environment on the development of traits and characteristics in individual organisms

Since our chief minority group, numerically, is the Negro, somewhat more attention is focused on this group in the discussion that follows than on any other single group. This is, however, merely a writing convenience. It will be clear to the teacher that the facts and observations which are valid for the Negro are, in general, valid for all groups of people.

THE NATURE OF PREJUDICE

A prejudice is a subintellectual development in the human personality. By definition, it is a prejudgment—a belief or attitude, and a tendency to act, which has grown without the benefit of critical thought processes. Thus, a prejudice may be of positive social value, or it may be antisocial. But it is always unreasoned.

Racial prejudice represents an uncritical viewpoint about groups of people that is not only antisocial but distinctly antiscientific, for it represents overgeneralization, often includes pure superstition, and ignores demonstrable evidence. It would appear, therefore, that the science teacher has an excellent opportunity as well as a definite responsibility, both as a leader of young people in a democracy and as a representative of the fields of science, their methods, hypotheses, and principles, to counter racial prejudice through his teaching.

The difficulty rests in the fact that a prejudice, being subintellectual, is not completely amenable to modification through intellectual processes.

THE CONTRIBUTION OF SCIENCE TEACHING TO INTERCULTURAL UNDERSTANDING

There is some evidence, however, that a significant contribution can be made to the lessening of racial prejudice through science teaching. Two examples may be given. A college class in general biology taught by the author was given a questionnaire designed, among other things, to detect prejudiced opinions and fallacious opinions about racial, national, ethnic, and religious groups.

One item, for example, ran as follows:

> Suppose that at birth one hundred Negro infants were, by some modern alchemy, made indistinguishable in all observable physical characteristics from as many white infants. Suppose further that these infants were adopted into white homes by adults who assumed them to be white. As these children grew into maturity (a) would their personalities and level of intelligence as a group have been grossly different from that of a comparable group of actually white children adopted into white homes, (b) would they have been somewhat different, or (c) would there have been no differences at all?

Opportunity was also given on each of the questions for the respondent to

indicate that he did not know. The responses of over one hundred biology students disclosed an approximate 30 per cent with some degree of racial prejudice or misinformation.

Following the course of instruction, in which anthropological, sociological, and genetical data were presented on the general question of racism, a comparable questionnaire was given to the students. Responses were again anonymous. Precisely one student showed evidences of racial prejudice or factual misinformation at this time. It must be recognized that, since the responses were anonymous, the possible pressure of the instructor in eliciting the "correct responses" was slight.

The other example is reported by Otto Klineberg, who refers to experiments of Murphy and Newcomb. These experiments showed that information on racial matters resulted, in their investigations, in no change in attitudes in some, in some change in a substantial proportion of those under investigation, and in no changes in the opposite direction, that is, toward greater prejudice.

It is obvious, of course, that paper and pencil responses, even though anonymous, do not necessarily reflect the action and tendencies toward action of the respondents. The responsibility of the science teacher does not stop with a dispassionate presentation of factual scientific data. Several excellent publications have dealt with what teachers have done, with encouraging results. A recent publication[1] presents, as a resource unit, materials that teachers of science, social studies, and English can use individually or as a professional team.

THE CLASSIFICATION OF MAN

Readings and general discussion should make clear to the students that the genus *Homo*, unlike most genera, does not have a series of species. There is but one present species—*sapiens*—to which every man belongs, whether he is a Formosan headhunter or an Alaskan Eskimo. This is demonstrated by the interfertility of all groups of man (the usual index of species difference is lack of interfertility). It is further demonstrated by the tremendous number of common physical characteristics and the paucity and superficiality of differing characteristics.

Another point to be made clear is that all attempts to find "pure" racial characteristics (variety characteristics) that would separate and completely distinguish groups of mankind have failed. In zoology, a variety (race) has certain distinguishing characteristics. If such characteristics as broad nose, prognathism, black pigmentation, and kinky hair were to serve as racial criteria, it would be necessary to find them exclusively in one group, such as the Negroes. Although these traits are found dominantly among this group—which is the reason, of course, why we designate the Negro group as a race—they are also found in vary-

[1] William Van Til, John J. DeBoer, R. Will Burnett, and Kathleen C. Ogden, *Democracy Demands It: A Resource Unit for Intercultural Education in the High School* (New York: Harper & Brothers, 1950).

ing degrees and in varying combinations among non-Negroes. Unlike the situation in zoology and botany, distinct and exclusive racial characteristics are not found in mankind. In other words, there are no "pure" races of man.

The usual characteristics by which the races are commonly classified support the contention that there are no "pure" races of man and should be explored. The following data may be helpful to the teacher in this exploration.

Skin color. All races have the same pigmentation materials. The differences found in skin color are, therefore, quantitative, not qualitative. Despite this fact, skin color has been more commonly used than any other single criterion to separate groups of mankind. We have the white-skinned, or Caucasoids; the yellow-skinned, or Mongoloids; and the black-skinned, or Negroids. Actually, the range of skin color in each of these groups is very great and overlaps. There are whites (certain East Indians, for example) whose skins are darker than the skins of some groups of Negroes.

Eye color and eye form. These characteristics are largely useless as a criterion. Dark eyes are common to all races. Blue eyes are found in all groups, even among "purebred" Negroes. The "slanting" eye of the Mongoloid Asiatic is caused by a fold of skin, the epicanthic fold, that covers the inner angle of the eye. Actually, this occurs in infancy among many whites. It occurs among some Negroes. Although the American Indian is a Mongoloid, he does not have the fold.

Hair form. Hair of any color may be found in any racial group; hence this characteristic is useless as a criterion. There are *typical* hair forms, however. Straight hair is typical of Chinese and Eskimos. Wavy hair is typical of Caucasoids. Wooly or kinky hair is typical of Negroes and Melanesians. But Australian Negroes (Australoids) have smooth wavy hair. Caucasoids actually have all forms. In short, hair form does not allow exclusive groupings.

Shape of nose. Nose shapes vary tremendously among the races, although the flat, broad nostril is more typical of the Negro than the Caucasian.

Body stature. According to anthropologists, the tallest and the shortest groups ever measured are both Negro groups. Stature is useless as a criterion.

Cephalic index. There are three major types: dolichocephalic with an index of under 75; mesocephalic, with an index of 75–80; and brachycephalic, with an index of over 80. (Index refers to the ratio of breadth of skull to length, expressed as a percentage.) Although there are group tendencies with respect to shape of skull, each racial group has all sorts of skull shapes. It is a useless criterion in distinguishing groups of people.

This difficulty in classifying man is emphasized by Ruth Benedict in reporting the study of Anders Retzius, who measured thousands of individuals in Sweden. He found that only 11 per cent of the Swedes conformed to the Swedish stereotype of tallness, blond hair, blue eyes, fair skin, and dolichocephalism.[2]

The question, "How many races are there?" merits brief attention by students.

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[2] Ruth Benedict, *Race: Science and Politics* (New York: Modern Age, Inc., 1940), p. 49.

Discussion based upon the foregoing should have made it clear that there are *no* clear-cut division lines between peoples. We might settle for two races (which is Franz Boas' suggestion—Mongoloid and Negroid), or we might have as many as ten or twenty races. However, the more one attempts to separate groups of mankind the more trouble he finds himself in. Commonly the following three groupings are used. The general characteristics of each are given.

1. *Caucasoid.* Rather hairy, hair wavy to curly, straight eyes, fairly high thin nose, low prognathism. (Note that "white skin" cannot be used, although this is the common name given to this group. The color of the skin is much too variable to be used.)
2. *Mongoloid.* Very little facial and body hair, hair on the head straight. (Slant eye holds only for certain groups, skin color varies and cannot be used as a criterion.)
3. *Negroid.* Skin color, in general, does distinguish this group from other two groups. Keep in mind, however, that certain Caucasoids have skin color darker than some Negroes. Really, it would be better to say simply that there is the darkest range of skin color commonly found here. Kinky hair, thick lips, prognathism, flat nose are commonly found in this group.

THE ORIGIN OF RACES

It may be found valuable to discuss the history of past species of manlike creatures with the class. Out of this discussion and study should come a recognition of the fact that most evidence points to the existence of a common ancestral *Homo sapiens* from which all present races have sprung. (Such, at least, is the common anthropological judgment.) Evidence of this common ancestral type is found in the interfertility of races, already referred to, and in the tremendously great common pool of genetic characteristics. Very few differences in basic traits can be demonstrated. If separate races developed from separate primitive subhuman stocks, vast differences in such basic traits should be more demonstrable.

Discussion of the dispersal, migrations, and undoubted isolation of small groups of people for long periods of time may be profitable in developing understandings of how mutations and inbreeding probably developed racial differences. After millions of years of common ancestry, culminating in a common type of *Homo sapiens,* the dispersal and isolation of small groups of man might have provided opportunity for mutations to arise. These would have resulted in the variations detected today as racial differences, which have been inbred sufficiently for these superficial subgroupings to be made.

A point of possible emphasis is the relatively vast amount of time in which man had a common ancestry (the millions of years leading up to Cro-Magnon, the first member of our species of which we have any certain record) compared

with the relatively short time that has elapsed since then, during which dispersal, isolation of small groups, mutations and their inbreedings have had a chance to operate. (Cro-Magnon came into Europe some thirty thousand years ago.) The point of this emphasis is, of course, that what is common among mankind is tremendously greater than the differences could possibly be.

It may be of interest to the student to learn that from the biological point of view we have no evidence that any group of mankind today is a whit superior to the Cro-Magnon cave man. Evolution since that time has not been biological to any known degree; that is, the time span has been too short for distinctive change to have been likely, and none is detectable on the bases of the physical measurements that are possible. Change has been cultural. A Cro-Magnon, if raised from infancy in a New York apartment today, would probably be indistinguishable in ability and personality from the average New Yorker. The same could also be said of an African barbarian if he could be made physically indistinguishable from an Anglo-Saxon white.

There is evidence that the dispersed groups of mankind had, after a few thousand years, so increased in numbers and developed such migratory abilities that they merged and blended, time after time, thus merging gene pools and losing any "racial purity" that might be ascribed to the few superficial traits that ever distinguished them. Students may profit from discussion of this general fact; for example, into Ireland came Scandinavians, Asturians from coastal Spain, Spaniards, Celts, Campignians from France or Denmark, Norsemen, Englishmen, Germanic tribes, Huns, Romans, Ligurians from northern Italy, and Arabs.[3]

PHYSICAL DIFFERENCES AND SIMILARITIES AMONG RACES

Students might profit from a consideration of blood groups and the complete compatibility of blood factors between groups of men. This compatibility and the fact that the same range (although not in the same proportions) of types exist in all groups of men indicates the common genetic background of such groups. Actually, counting the famous Rh and similar factors, there are more than 40 groups and 360 varieties of blood factors. Although there are tendencies for greater or lesser proportions of these blood factors to exist in certain groups, all groups have all of them—another demonstration of the common genetic pool from which all peoples have drawn.[4]

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[3] See the charts entitled "Melting Pots of Europe" in Amram Scheinfeld, *You and Heredity* (Philadelphia: Frederick A. Stokes Company, 1939), pages 344–346. See also Benedict, *op. cit.*, Chapters 3 and 4, on the picture of man's origin and migration.

[4] See any genetics textbook or Chapter 28 of Scheinfeld, *op. cit.*, for the operation of genes in blood types A, B, AB, and O. See *Hygeia* for September, 1945, for an account of other factors involved in blood typing.

The significant and scientifically accurate point that the teacher can make in this discussion of blood grouping is well expressed by Ruth Benedict.[5]

> Blood types are strictly hereditary and very stable; an individual having a blood type A, for example, must have had one or both parents whose blood type was A. Therefore, when different blood types are present in any population, it is one of the surest signs of mixed ancestry. But even such isolated races as the aboriginal Australians have a high percentage of blood group A, which is that most characteristic of Western Europe. And high percentages of blood group B, that is most characteristic of India and Eastern Asia, are found throughout Europe. The evidence from the study of blood groups emphasizes in the strongest possible manner the great amount of biological mixture that must have taken place from the earliest times.

Blood typing of students is quite feasible, although expensive. Group A and Group B sera are obtainable from producers of biologics, such as Parke Davis. The teacher may prefer to arrange for the class to observe blood-grouping techniques at the laboratories of a local hospital or at a private laboratory. If the members of the class want to attempt their own typing, aseptic precautions should, of course, be observed. Any standard textbook on blood-grouping techniques or serology will provide the interested teacher with background information. A local doctor will probably lend such a reference book from his personal library.

During World War II, blood plasma was collected in blood banks and used to save innumerable lives on the battlegrounds of the world. Blood plasma is a constant, of course, so far as type is concerned. Despite the fact that Negro plasma is quite indistinguishable from white plasma, pressures caused the Red Cross to refuse, or keep separate, blood from Negro donors at some collection centers during the early part of the war. (The film *Boundary Lines* dramatizes an incident relevant to this prejudice and is worth seeing and discussing as a class.) The fact that prejudice operated against such a vital service as providing life-giving blood for American soldiers merits class discussion. The students may find interest in the fact that the development of the processes of utilizing, storing, and handling blood plasma was in large measure the result of the work of the famous Dr. Charles R. Drew, Professor of Surgery, Howard University. Dr. Drew is not only an international authority on blood plasma, he is also a Negro.

Not because racial physical differences are important, but precisely because they are of no significance and yet form a common rationalization for prejudice in the minds of many people, the teacher may care to provide for as much attention to the problem as the interest and concern of the class may warrant. It is

[5] Ruth Benedict, *Race: Science and Politics* (New York: Modern Age, Inc., 1940), pp. 44–45. Reprinted by permission.

probably wise not to raise such issues (on the principle that stereotypes, like superstitions in general, may actually be promulgated by repetition of expression), unless there is evidence that the students do have misinformation and stereotyped notions. It would appear to be wise to consider any observations or questions in this category that are raised by the students. Various reference books will help the teacher in the process.[6] Among the questions commonly asked by children and the misconceptions commonly held, appear the following that might, with profit, be discussed by the class.

A commonly raised question is one referring to the more "primitive" or "apelike" characteristic of one group of people compared with other groups. This question, in the first place, is, of course, based upon the false assumption that lines of evolution are orthogenetic, so that some groups of people represent certain stages of evolutionary development and others represent further stages in evolutionary progress. However, the question is often raised and should be handled when it is raised.

The most noticeable characteristic of the ape is, perhaps, his hairiness. Caucasoids are the hairiest of the human race, Negroids the least hairy. The ape has straight hair. The Mongoloid has straight hair, the Caucasoid smooth hair, and the Negro has kinky hair. The ape has thin lips. The Caucasoid has thin lips, and the Negro has thick lips. What does all this prove? Absolutely nothing, of course. Some such brief review should be coupled with an analysis of how irrelevant the whole analysis actually is. No one now believes that we descended from apes. Rather, there is considerable evidence that the apes and modern man evolved from a common ancestry. There is even more evidence that, late in evolutionary development, the single species *Homo sapiens* emerged as the common ancestral type which all races still represent. In short, the races of mankind are not on various positions in the evolutionary tree. They are all in the same position and are, evolutionarily speaking, identical.

Students sometimes wonder whether races and groups of people vary significantly in the "primitive" or vestigial (presently nonfunctional) traits. The answer is clearly no. All of us have over two hundred distinct vestiges of no apparent present use. These range from the appendix to musculatures that apparently, in some ancestral form, wiggled our scalp, moved our ears, and even controlled our presently nonexistent tails. All races have these vestiges—evidence, again, of a common ancestry for vast reaches of time.

According to Ethel Alpenfels, a common question of young persons is in reference to the possibility that races smell different. Do races smell different

[6] See, in particular, Otto Klineberg, *Race Differences* (New York: Harper & Brothers, 1935), on mental and psychological aspects; Ruth Benedict, *op. cit.;* Ethel Alpenfels, *Sense and Nonsense about Race* (New York: Friendship Press, 1946); Ruth Benedict and Gene Weltfish, *The Races of Mankind* (New York: Public Affairs Committee, Inc., 1943), a brief summary of some materials from *Race: Science and Politics.*

from one another? Sweat glands are modified hair follicles. There are two types of sweat glands, actually, and all people have both kinds. There is a difference in the number of sweat glands typically obtaining among different races. Negroes have more than whites. However, white women typically have more than do white men. Similarly, whites who live in the United States typically have fewer than Caucasoids who live, for example, in the hotter sections of India. There appears to be some difference correlated with generations of life in different climates.

Odor of perspiration is related to health, diet, and bodily hygiene. As the science teacher knows, urea is excreted by the sweat glands in varying amounts. That there are no racial differences in the odor of perspiration is demonstrated (as far as the demonstration went) in a report of Alpenfels of an experiment conducted by anthropologist E. A. Hooton of Harvard. Hooton secured samples of perspiration from individuals of different racial groups. These samples were submitted to a group of blindfolded judges. The judges could not distinguish racial differences, although they could distinguish differences in the odors of the separate samples. (It is of passing interest that one judge was a Chinese, and the most disagreeable odor he detected turned out to be that of the perspiration of a white man.)

Obviously, a common laborer is apt to sweat more and, therefore, smell more than a professional man. As Negroes in many places are restricted to laboring jobs, as they often have few facilities for high standards of bodily cleanliness, and as, finally, they often have inadequate diets for economic reasons, it may be expected—under such conditions—that they may have greater body odor than more fortunate human beings, whether Negro or white.

There are modal tendencies in cephalic indexes in certain groups of people—dolichocephalicism, for example, is common in Negroes. But it may be useful to ignore distinctions in cephalic indexes *between* racial groups, and to concentrate, first, on what has been found regarding correlations between intelligence and head size and form in the general population. This allows the variable of head size or of form to stand uncomplicated by other possible variables.

Scientists have not discovered any relation between intelligence and head size or form in the general population. Studies of brain size among men of different occupations, ranging from professional men to unskilled laborers, have disclosed no particular correlation between brain size or dimensions and demonstrated achievements. Some of the most brilliant men have had large brains, and some of the greatest have had exceedingly small brains, compared with the general population.

PERSONALITY AND RACIAL DIFFERENCES

Before students examine the bases of discoverable personality and intelligence differences between groups of people, it is desirable for them to consider rather

carefully what forms any personality. ("Personality" is here used in the psychological sense, meaning all the constitutional, mental, emotional, and social characteristics of an individual.) Thus, in an area of far less prejudice, any understandings that develop may be transferred to a consideration of hypothesized differences in peoples. Many of the personality traits commonly assumed to be typical of large groups of people simply do not appear in those groups more commonly than they do in other groups. Where such traits do appear, the question of causative factors has still to be resolved.

What is the genetic basis of the personality? If the personality of man were ascribable to a single gene, or to a limited few, it would be possible to assume that the same limited number of mutations that produced the black skin and the typical thick lips of the Negro might have produced a personality type that bred true. If the personality must be ascribed to the operation of a large number of genes, then such an assumption would be demonstrably false; for what we know about the independent segregation of genes in meiosis would make it false.

Before young persons can engage intelligently in such an analysis, it is necessary that they have some basic understanding of genetics, including the Mendelian laws (in which the inheritance of unit characteristics and gene segregation in reduction division is emphasized), the theory of mutation, or rather the fact of mutation and theories to account for its mechanics, and a general understanding of the simple mathematics of independent assortment when a large number of genes are involved.

The student should be brought to recognize that personality is compounded of a large number of gene effects coupled with a tremendous range of environmental factors. Class discussion may profitably center on a consideration of some of the probable physical bases of personality (gene-controlled), such as the gross and detailed structure of the brain and nervous system, the structure and functioning of most, if not all, of the ductless glands, and the structure and functioning of the digestive glands. (An inherited malfunctioning liver or duodenum almost certainly would affect the personality of its possessor.)

The foregoing is, of course, a brief and necessarily limited sampling of the many genetically controlled body structures, the functioning of which certainly has a part to play in one's personality. Yet, even in these few physical structures, a large number of separate genes must theoretically be involved. It is impossible to assume that these genes are so linked in reduction division that they "throw" as a unit.

Class discussion of the ways in which cultural values, mores, and conceptions of the beautiful, the good, and the bad may shape and develop personality traits (nongenetically determined traits) may be rewarding. The students should sample some of the environmental and cultural bases of personality development.

For example, the class may consider how a fat girl in American culture inevitably has her personality shaped differently than if she were of the slim

"American beauty" type. There are, of course, cultures where the fat girl would be admired for her beauty of form, and the slim "beautiful" American girl would be largely ignored or even laughed at. Obviously, the personalities of both slim girls and fat girls would tend to be differently molded in different cultures. Fatness, then, is not *natively* associated with any particular type of personality. It depends upon the qualities the culture sees in fatness. The same can, of course, be said of slant eyes or black skin.

Similar analyses can be made of tall girls, short girls, skinny boys, muscular boys, receding chins, jutting chins, long-headed people, and round-headed people. Personality does not conform to any physical concomitants of such superficial order. It does conform to psychic pressures and to popular stereotypes of how a fat person or a person with a receding chin behaves. (Attention to the pseudo science of phrenology may be of interest at this point.)

The "halo effect" of stereotyping in producing actual types of psychic pressure should be explored by the class. It may be of value to discuss the fact that, in former years (and at the present in some cultures and to some extent in American life), women were considered intellectually inferior to men. Psychometric methods have demonstrated the essential equality of the sexes, even in mathematical and mechanical aptitude. But the mores of our culture have made it unlikely for women, as a group, to have the same degree of intellectual attainment, particularly in mechanical fields. This psychic environment has caused even the women themselves to feel that they "just aren't mechanically inclined." *Rosie the Riveter* of war days and the woman mechanic in such countries as Russia have helped to dispel this notion somewhat, but the stereotype still obtains. (There are, of course, cultures in which the European stereotypes of masculinity and feminity are neutralized and even largely reversed. See the works of Margaret Mead and Ruth Benedict.) The foregoing analysis can be applied, by analogy, to the racial stereotypes. If that analysis precedes a consideration of racial stereotypes, there may be a high transfer value into this prejudicial field.

The class may care to make an analysis of the possible genetic factors involved in something as relatively simple as a person's height. Hypothesizing the number of different genes operating in such a simple thing as height may clarify the tremendous number presumably operating in a thing as complex as intelligence or personality.

The problem is one of applying what is known about the unit nature of genes and their independent assortment in meiosis to hypothesizing roughly how many *different* combinations might result.

Assume that height is the result of the operations of ten different unit characters (the number chosen here is completely arbitrary) as follows: a gene for the shape of the heel bone, one for the height of the arch, one for the curve of the tibia, one for the length of the femur, one for the articulation slant of the hip bones, one for the depth of the cartilage pads of the vertebral column, one for the thickness of the vertebrae, one for the general curve pattern of the total

spinal column, and one for the height of the skull pan. (These are not, of course, known separate genotypic factors, but it is assumed for the analysis that at least ten genes are in operation to produce the total height of the body.)

What chance, if ten such genes are in operation, has an offspring to have precisely the same set of height factors as his father, if the father and mother differed in each of these ten hypothesized genes (essentially a decahybrid cross of purebreds). He would have 1 chance in 1,024 possibilities—that is, 2 to the tenth power. It would, then, be improbable that a child would exactly conform to one parental type on such a relatively simple combination of factors as we here assume body height to be.

What, then, would be the probabilities that a child would conform to a parental type in personality? Here we must assume that far more than ten genes are operating. Probably hundreds of genes are in operation. The possible combinations (resulting in distinct phenotypes) would, therefore, number in the high millions.

Continuing the argument further, and assuming that the simple unitary mutations that produced our so-called races occurred very recently (say thirty thousand years ago) from a common genetic pool, it can be seen that the likelihood—with, for example, a mutation producing black skin—that any significant grouping of "personality genes" were neatly separated to make the black skinned mutant a distinct *genetic* or *genotypic* personality is so small as to be ridiculous. To assume that the descendants of the original black mutant, even when we hypothesize considerable inbreeding, would result in a people with a particular inborn or genotypic personality tendency is even more ridiculous.

The foregoing argument may be applied, as well, to what we call "intelligence." Unless it is assumed that there is a single gene (or small group of genes) producing the total genotype for mental ability of an individual, it is ridiculous to say that the races of mankind, which through eons of evolutionary history were one stock, would differ materially in the genetic basis of their intelligence.

The teacher may care to provide a more disciplined approach to the analysis of genetic factors involved in height and mental ability. Reference to Amram Scheinfeld's *You and Heredity* will be useful in this connection. It is convenient to assume a limited number of chromosomes at the beginning of the analysis in order that students may see the combinations that are theoretically possible with a limited number of factors before analyzing the possibilities with longer numbers. Assuming four chromosomes, for example, received from the mother and four from the father, there would be 16 possible combinations of chromosomes in the sperm or egg resulting from the reduction division. Adding one more chromosome pair provides 32 possible combinations. Adding another pair provides 64 possible combinations in the sperm or egg, and so forth. Man has, of course, twenty-four pairs of chromosomes. Each parent can, therefore, produce 16,777,216 different combinations of chromosomes. The gene combinations, par-

ticularly when we allow for a certain amount of crossing over, are really stupendous.

Even ignoring the crossing over, the story is not complete. At the time of fertilization of the egg, any one of the 16,777,216 different types of sperms has a theoretically equal chance of combining with any one of 16,777,216 different types of eggs. The possible combinations of chromosomes found in a fertilized egg are in the trillions—about 300,000,000,000,000 different possibilities, to be more exact. The student should be brought to see that this means that each person is a unique and really individual being and to realize that it is an error to look at any individual as a subsumption under a racial category.

THE EFFECT OF THE ENVIRONMENT ON ORGANISMS

This, the last group of proposed activities suggested, is also the largest group. The over-all purpose of these suggested activities is to illustrate that physical and psychic influences in the environment heavily determine the degree to which genetic potentialities become actualities. A second, and closely related, purpose is to cause students to recognize that certain minority groups of people are almost universally subject to certain psychic, if not physical, restrictions. Paraphrasing Margaret Mead, as long as certain groups of people are considered more stupid or more antisocial, that long will they tend to become and remain so. A third purpose of this group of suggested activities is to illustrate that, regardless of environmental factors, we find tremendous variations in individuals of all groups of people, with no group having a monopoly on either the good or the bad traits.

Students may be interested in experimental plantings of fast-growing seeds under different environmental conditions. If a sufficiently large number of such seeds are planted under each set of experimental conditions (assuming, of course, that seeds for each planting were from the same package), the assumption is relatively safe that the same range of genetic types will exist in all plantings. The variable conditions may be of temperature, overcrowding, soil type, light, and moisture. The class should observe carefully the effects of these variables on the apparent health, speed of growth, and mature size of the plants. Discussion of the effects of the variables on the apparent genetic promise in the seeds will be more fruitful if one planting is given optimum conditions for development.

There are many observations in nature that bear on the fact that the potentiality of the biological inheritance depends for fulfillment upon the environmental, or cultural, inheritance. White grass under a board or the white shoots from a potato stored in the dark will serve for a worthwhile discussion. The genetic basis for chlorophyll development has obviously been thwarted by an unstimulating environment.

Field trips may be taken for the purpose of observing the effects of the environ-

The environment heavily influences the degree to which the genetic potential of an organism will be realized. The influence of environment on living organisms can be studied both in the laboratory and in the field. (Courtesy of Cleveland Public Schools)

ment on common plant varieties. Observations of planted row crops, such as corn, where the soil has eroded at the crown of a slope will prove interesting. The stunting influence of the environment will, in such instances, be dramatically clear.

Students who have traveled through mountainous country may care to discuss the stunting effect of altitude, winds, and cold from their remembered observations. The entire study of life zones and the dominance of forms of life in ecological communities rising to climax conditions may be rewarding in this connection.

Extended diet experiments with white rats are useful. They may be performed to illustrate the effect of malnutrition not only on physical health but, as well, on personality. The listlessness, laziness, and improvidence resulting from a diet deficient in energy-producing foods is particularly interesting. The diet is quite easy to arrange.[7]

The fact that a gene can produce a particular characteristic in one environment and another characteristic in a different environment has been demonstrated repeatedly. The fact that we inherit genes giving the promise of characteristics

[7] For an account of one set of experiments, together with directions for the diets, see R. Will Burnett, "Diet Experiments in the High School Laboratory," *School Science and Mathematics,* 38, No. 3, 242–249 (March), 1938.

rather than inheriting the characteristic itself cannot be too strongly emphasized by the teacher when dealing with racial and intercultural problems. The teacher will be familiar with many examples of this fact, such as the coloration of fur in such animals as the ermine in northern winters compared with the coloration of their fur in summer months. A rather fascinating example of the fact under discussion is given by Gunnar Dahlberg in his *Race, Reason, and Rubbish.* Dahlberg presents an account and pictures of a Russian rabbit in which black pigmentation is normally confined to the extremities. A geneticist conjectured that the black pigmented fur was confined to the extremities simply because these parts of the body got cold. Fur elsewhere on the rabbit is normally white. The geneticist shaved the hair off the back of the animal in the middle of winter and forced it to live outdoors. As he had expected, the hair that grew over the shaved region was black. In short, the rabbit possessed genes that, given a low temperature directly on the skin of any part of its body, would produce black fur. The same genes, given a warm temperature on the surface of the body, would produce white fur.

Consider, with the class, what generalizations may safely be made from the foregoing experiments and observations with reference to the human organism when it develops under conditions such as those that may be found in slums, ghettos, and poverty-striken regions in general. Dogmatism and overgeneralizations should, of course, be avoided. But support for the hypothesis that a somewhat similar "stunting" of human personality may result from a depressed human environment will be found in experimental data reported in the studies mentioned in the following pages.

The following readings are important, for they represent a brief, but balanced, sampling of experimental data on the effect of the environment on human personality and development. These may be discussed by the class with profit. Since many teachers will not have access to the reference materials listed, brief reports of the more significant points and conclusions are here included in the listings.

Dahlberg, Swedish geneticist and director of the State Institute of Human Genetics at the University of Upsala, has written a summary of what we know about identical uniovular and fraternal (dizygotic) twins. His conclusions about monozygotic twins (having, of course, identical genetic structure) are of particular interest in a discussion of the effects of environment. They are[8]

> 1. Differences to which uniovular twins are exposed are not usually great. During the period of growth they customarily get the same food, the same early training, or school teaching; and in most respects, uniovular twins are amazingly alike.
> 2. . . . differences of mental characteristics, measurably by tests more or less appropriately called "intelligence tests" are comparatively small among uniovular . . . twins.

[8] Gunnar Dahlberg, *Twin Births and Twins from an Hereditary Point of View* (Stockholm: Bokforlags a.–b. Tidens Tryckeri, 1926).

3. In the opinion of the writer, one observation which comes out of such work is that temperamental differences are comparatively great among uniovular twins.

Conclusion 3 is, if correct, of tremendous import. It is to be expected that identical twins would be remarkably similar in physical build regardless of all except the most extreme differences in environment. If, as Dahlberg states, the physical environment of identical twins is commonly similar, great differences in mental characteristics would not be expected. But, as any child psychologist knows, the psychic environment afforded siblings in a home, school, and community tends to be a different thing for one child than it is for his twin. Therefore, despite genetic identity, one could reasonably expect differences in personality, "temperamental differences," to use Dahlberg's term. The environmental pressures influencing personality development are apt to be different on any two children, even though they are raised in the same home and by the same parents. The results of experimental investigation led Dahlberg to believe that these expectations are fulfilled. It is to be noted, however, that other investigators have disagreed with this opinion. The area is, nonetheless, worth discussion.

There are a few cases of abandoned children who grew up without human companions that are reasonably well documented. Such cases merit brief consideration by the class. Benedict presents a short account of Linnaeus' classification of such children as a separate species. Benedict states:[9]

> In Europe, in other centuries, when children were occasionally found who had been abandoned and had maintained themselves in forests apart from other human beings, they were all so much alike that Linnaeus classified them as a distinct species, *Homo ferus*, and supposed that they were a kind of gnome that man seldom ran across. He could not conceive that these half-witted brutes were born human, these creatures with no interest in what went on about them, rocking themselves rhythmically back and forth like some wild animal in a zoo, with organs of speech and hearing that could hardly be trained to do service, who withstood freezing weather in rags and plucked potatoes out of boiling water without discomfort. There is no doubt, of course, that they were children abandoned in infancy, and what they had all of them lacked was association with their kind, through which alone man's faculties are sharpened and given form.

Millions of American children grow up in unstimulating environments. Some of these children live under conditions that are extremely thwarting of genetic promise. For those who have witnessed these conditions and the lack of developmental opportunities for certain groups of people (for example, many of the Navajo Indians, certain Mexican groups, Negro groups in some places and

[9] Ruth Benedict, *Patterns of Culture* (Boston: Houghton Mifflin Company, 1943), pp. 12–13. Reprinted by permission.

regions), the extreme cases of the abandoned children simply make somewhat surprising the fact that warped and stunted personalities in such American groups are not more common. Thus the area merits brief analysis and discussion.

A fair number of investigations have been made on personality characteristics of various people. The instruments used in determining personality characteristics are of questionable validity and have consistently been so reported by the investigators themselves. Nonetheless, the findings of these studies are of interest. A summary of them has been published by Otto Klineberg.[10]

The particular part of the volume here referred to deals with peoples other than Negroes, although studies of Negroes make up the bulk of the reported studies. Of particular interest is the study by S. L. Pressey and L. C. Pressey on Indian and white children. They found that American Indian children tend to have emotional ages lagging considerably behind that of age mates among whites. They point out that there is the possibility that this is because ". . . his environment has been so simplified that adjustment on a childish level is good enough." In their second study, Pressey and Pressey report that they tested Indians from twenty-two tribes and classified them according to admixture with whites as fullbloods, three-quarter-breeds, half-breeds, and quarter-breeds. They found that emotional retardation differed little for the four groups. They state,

> In no instance does there appear to be any real tendency for more admixture of white blood to result in an approach of the scores to the white norms, from which the emotional ages are derived. . . . The data certainly suggest a triumph for the environmentalists. Apparently if a person of any degree of blood lives and behaves like an Indian, he thinks and feels like an Indian—and for all social purposes, is an Indian.

The implications of this statement should be made clear to students, and free discussion should be encouraged.

Murdock studied the influence of cultural benefits and values on personality traits.[11] Using a difficult motor test that was impossible to accomplish with the eyes closed, he assumed that success with the eyes closed was evidence of cheating; that is, the child simply had to open his eyes to succeed. It is of interest that Japanese children cheated much less commonly than did Anglo-Saxon children. Neither from a genetic nor an anthropological point of view could one assume that the Japanese were *natively* more honest, as a group, than the Anglo-Saxon children. The probability is that there is a markedly different cultural background or cultural code of morality in the two groups.

Another study of cheating and deception[12] showed the following in regard to

[10] Otto Klineberg (ed.), *Characteristics of the American Negro* (New York: Harper & Brothers, 1934) Part III, "Experimental Studies of Negro Personality."

[11] K. Murdock, "A Study of Differences Found between Races in Intellect and Morality," *School and Society*, 22:628–632, 659–664, 1925.

[12] H. L. Hartshorne and M. A. May, *Studies in Deceit* (New York: The Macmillan Company, 1928).

Jewish children and Christian children. In general, in this experimental study, Christian children cheated once in every three opportunities; Jewish children, in a school of low socioeconomic-status children, cheated once in every five opportunities. Obvious material for discussion is forthcoming from these data. Not ethnic grouping, but socioeconomic level, "family pride," and similar factors correlate with deception and cheating.

Klineberg[13] summarizes several studies on the musical aptitude and ability of the Negro and the white. The careful reader will note the invalidity of many of the "white man's tests" when applied to deviate groups and will find that the results are contradictory. However, whatever the basis in culture or genes, the Negro is apparently not the musical person the common stereotype holds him to be. Klineberg states, "The stereotype of the Negro as musical is not substantiated by these test results, since the Negro scores are in general inferior to those of the whites."

The insightful teacher can tie the results of such investigations into the general and common unscientific error of overgeneralizing on limited data. The tendency to place an individual into a categorical stereotype is not only dangerously undemocratic, it is definitely antiscientific.

The following data may be discussed with value. During World War I, intelligence tests were applied to the American Expeditionary Forces (A.E.F.). When the scores from these tests were arranged by racial and national groupings, it was found that the average mental age of Negroes and whites was as follows:

Whites	13.1 years
Negroes	10.4 years

Other results were that people of northern European ancestry scored higher as a group than did those of southern European ancestry. Those of Mexican, Indian, Polish, and Italian ancestry—to report a few examples—also scored low on the tests, as groups. Intelligence testing was relatively new at this time, and a judgment grew that these results represented actual differences in *native* intelligence. Considerable research since that time has caused psychologists to doubt this conclusion. For one thing, these tests were, again, "white man's tests" and of a specific cultural orientation at that. Further, it is quite obvious that what is tested on the standard test forms represents what is learned. Although it is true that one with an idiot's inability to learn would score very low on such tests, it is also theoretically possible that one with a potential genius's native endowment who had lived in an unstimulating environment and who had not been subjected to the usual processes of education would also score very low on the test. There are other grievous inadequacies in intelligence testing that are presented in publications devoted to the subject.

It is here sufficient to indicate that psychologists had reason to question whether the data derived from the scores of World War I intelligence tests represented racial differences or differences in environmental backgrounds. Consequently, the

[13] Klineberg, p. 128.

testers arranged the scores of the whites of southern states against the scores of the Negroes from northern states. When this was done, the following median scores were obtained.

Whites		*Negroes*	
Mississippi	41.25	New York	45.02
Kentucky	41.50	Illinois	47.35
Arkansas	41.55	Ohio	49.50

The implications of this are obvious. The Negroes from the more intellectually stimulating environments scored, on the average, consistently higher than did the whites, on the average, from the less intellectually stimulating environments. As the Negroes in the A.E.F. came predominantly from the South, it is reasonable to assume that they scored low because they were from intellectually unstimulating environments and not because they were Negroes. The same judgment could presumably be made as a substantial hypothesis regarding the relatively low scores of the Mexicans and the Indians.

Certain studies of Negroes in the South have shown an average I.Q. of about 75. Negroes in the South have been educated separately from whites and, of course, are commonly less well educated and subjected to less intellectually stimulating environments. In Los Angeles, to take one different region in which intelligence testing of Negroes has been conducted, Negro children are relatively few and are educated in the same schools and classrooms with the whites. Although they are subject to discriminatory practices that add up to less intellectually stimulating environments than those of the whites, the situation is less unfavorable than in the South. The average I.Q. of Negroes in Los Angeles was found to be 104.7.[14] The question has properly been raised whether or not the superiority of test scores of northern Negroes represented a selective migration of the brighter Negroes to the North. Klineberg[15] has made a careful study of the problem. He studied the school records in southern cities. These records disclosed that the I.Q. average of all emigrants to the North was almost exactly the same as the average of the entire Negro school population in those cities. In short, he found no evidence to support the hypothesis that the emigrant Negroes had higher intelligences (at the time they left the south) than did those who remained in the South.

Klineberg made another test of the hypothesis. If the relatively high scores of the northern emigrants who had lived in the North for some time were the result of selective migration of the brighter Negroes, then, presumably, length of residence in the North would not affect the scores. When he tested Negro children in New York schools, he found that the newest arrivals from the South had the lowest scores and that there was, in general, a rise of I.Q. proportionate to the length of residence in this more intellectually stimulating environment.

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[14] For a fuller account of these and other investigations, see T. R. Garth, *Race Psychology: A Study of Racial Mental Differences* (New York: McGraw-Hill Book Company, Inc., 1931).

[15] Klineberg, *Race Differences.*

The class should be brought to recognize that the Negroes as a group never have the same educational, economic, and social advantages as whites as a group. Furthermore, and this point has too often been neglected, psychic environment is tremendously real and influential in molding a personality. Although a Negro may grow up in great wealth with a material environment comparable to that of the upper class white, he is still, and constantly, subject to a psychic environment as a member of a minority class. He is subject to psychic pressures and discriminations that never permit him to forget that he is "different" and somehow a second-class man and citizen.

Even if it were possible to demonstrate that the native abilities of peoples vary —something that has not been demonstrated—there is incontrovertible evidence that all racial, national, ethnic, and religious groups contribute individuals to each decile of the intelligence scale and to each of any behavioral characteristics that might be specified. The student should, therefore, be helped to understand the danger of stereotyping and to recognize the democratic and scientific necessities of considering an individual in terms of what he is as an *individual*. In achieving this objective, the teacher may find it useful to use stereotypes in other than racial fields. She might ask such questions as the following and discuss the students' responses. Are all blondes frivolous? Are all fat men happy and good-natured? Are all men with receding ("weak") chins cowards? In discussing this question, it may be of interest to point out that a skeletal characteristic of the American Indian is a receding chin; the students will doubtless be aware of the historical stereotype of the bravery of certain tribes of American Indians. Are all Scotch "tight"? Are all Spanish romantic? Are all Americans money-mad? Stereotypes are almost endless, for they release the mind from the trouble of thinking. Students will volunteer many others for class consideration.

It might be rewarding for the class to study their newspapers and magazines for evidence of stereotypes in current news and in articles and stories. They may be taught to be more critical of "Shylock" stereotypes and of news items that report, "The Russians moved with true Slavic cunning." Countless examples of such thought-clouding stereotypes may be found in current literature and the classical literature. The damage that such stereotypes does to clear thinking should be discussed.

The modern American Indian has, of course, the same genetic structure, as a group, as did his warlike ancestors of frontier days. It may be worthwhile for students to read reports and studies of the characteristics of today's typical reservation brave and to compare him with his genetic prototype of a few years back and attempt to account for the difference. Equally interesting would be a discussion of the differences in judgment represented in the literature relative to the Japanese prior to and during World War II. The stereotype changed from that of a delicate, polite, peace-loving, and artistic people to that of a warlike, cruel, subhuman people. The class should consider the question, "Are there natively warlike and natively peaceful peoples or do circumstances tend to produce such apparent national characteristics?"

The foregoing material represents a general method of organizing science and related content and activities around a major problem for the purpose of developing important understandings, more critical thinking, and sounder attitudes in young people. The next chapter shows how one teacher worked with a common-learnings class to achieve much the same goals by using atomic energy as the content vehicle.

12

THE CORE PROGRAM IN ACTION: A CORE UNIT ON ATOMIC ENERGY

The account which follows illustrates both the procedures typically followed in core classes and how the problem approach and group planning create interest and provide the setting for significant learning activities. The reader may care to refer to Chapter 7, "Preplanning for Better Teaching," in connection with his reading of this chapter in order to understand better how such teachers as Mrs. Lindsey, the author of the following account, typically plan for unit teaching which employs a wide variety of references and other teaching materials.

I TAUGHT ATOMIC ENERGY[1]

It's fun to teach when students meet you at the door in the morning in order to tell you about an exciting article that they found the night before. When they are

[1] This account was written by Audry H. Lindsey, formerly a teacher at the University High School, University of Illinois. It was originally prepared at the request of the present author for inclusion in a special issue of an educational journal of which he was the editor. See "I Taught Atomic Energy," *Education* 71, No. 7:451–464 (March), 1951. The present account is slightly adapted from the original and is followed by statements made by students who were in Mrs. Lindsey's class. These statements also appeared originally in the same volume of *Education* under the title "We Studied Atomic Energy," pp. 465–469. Reprinted by permission.

anxious for class to start because they want to tell the class about what they've read. When they groan with disappointment and amazement when the bell rings. When a student calls you during summer vacation to ask you excitedly if you have seen the article that just came out. Teaching the exciting and timely story of atomic energy and its implications can do these things. I've experienced it.

Many people in education today feel the urgency for teaching information about the implications of the new era, the Atomic Age; but knotty problems still exist in many schools. Who shall teach this new material? Who is prepared to teach it? Where in the curriculum shall it be taught? What information should be taught? To what extent should there be teaching of the social, political, and moral consequences? What concepts can the students understand? Unfortunately, many still believe that the mysteries of atomic energy are something only the specialists in the field can understand.

A few days ago, a teacher from a European school visited my class. At the close of the period, with incredulity, she rapidly questioned me: "But how old are these boys and girls?" "Can they really understand such a subject?" "Where can they find information that they can read and understand?"

My experience has shown me that if boys and girls are given an opportunity to explore this vital topic, my biggest problem becomes one of trying to keep up with them.

I do not feel that I have definite answers to all these problems and do not propose to attempt to offer the reader a neat solution of them; I shall simply report as objectively as I can my experience in teaching atomic energy to freshman high school students during the past two years.

WHERE WAS IT TAUGHT?

The unit "What it means to live in the world with atomic energy," is a part of a Freshman Problems course—a common learnings course which meets two hours a day. The content of this course is made up of those problems common to the freshmen in our school.

Most of the subjects taught in our school are library centered and it is extremely important that every student be able to use all of the resources of the library efficiently. We believe that library skills can be taught more effectively if they are taught at a time when the student feels a definite use for them, rather than in an isolated situation.

Success in many of our high school classes also depends upon the student's ability to plan work with the teacher and the class; to participate in various kinds of presentations—individual, panel discussions, round table discussions, and upon his ability to work with groups in preparing these discussions. This topic offers excellent opportunity for giving trainng in these techniques.

Emphasis in this unit was also placed upon: developing the ability to keep and use a good notebook, i.e. skill in taking notes, organizing notes and studying from notes; learning to use common abbreviations, learning to organize materials for

written preparations; learning to organize and prepare materials for oral presentations such as the speech outline, use of examples and illustrations, use of visual aid materials; learning effective oral communication as an individual and in group discussions.

To teach these things, we had the problem of choosing a unit for exploration that would have group appeal, that would arouse enough curiosity that the students would be interested and eager to investigate and to seek information about it, that would be current enough that information would not only be found in books but also in periodicals and newspapers, and that would offer a great variety of resource materials. Since our library does not offer enough resource materials in any one topic for fifty freshmen to use at the same time, and since it would be difficult to find a single topic with intense appeal for that many, we chose three topics for exploration which we thought would fit these requirements: "Implications of the Air Age," "The Effect of Movies on American Life," and "Atomic Energy." The group was presented with some of the possibilities offered by each topic and each student was allowed to choose the topic which was most appealing to him. There was a teacher to direct the exploration of each topic. I have had the stimulating experience of exploring the topic of atomic energy with two different groups of students during the past two years.

A LOOK AT THE GROUPS

The groups have been made up of eighteen and twenty students each with approximately the same number of boys and girls in each. The ages ranged from eleven to fourteen, the reading abilities from seventh grade to senior high school with the majority having a reading ability of ninth grade level or above. The I.Q.'s ranged from 110 to some above 160 as measured by the Henmon Nelson Test of Mental Maturity.

All of my first group, with the exception of three, came from University faculty homes or homes of other professions. Thus, the majority had access to a variety of newspapers, magazines, and other materials at home. However, none of the parents of students in this group were specialists in any of the physical sciences or social studies.

My second group had an even representation of professional home backgrounds and backgrounds representing the military, business, and labor. A somewhat larger number in this group did not have access to an unusual amount of reading materials at home. Some members of this group, however, did the most extensive reading in the libraries of both the school and city and wrote to a variety of sources for information.

HOW WE STARTED OUR STUDY OF ATOMIC ENERGY

The room was prepared for the first meeting of the group with a display of books, magazine articles and pamphlets about atomic energy from my personal files and the library. A bulletin board of curiosity-arousing pictures and articles

was started. The second group also had notebooks prepared by the first group to examine.

After considerable discussion and many suggestions the first group decided to call their unit "Implications of Atomic Energy" and the second group chose "What it Means to Live in the World with Atomic Energy."

The first two hours were spent in a general exchange of information in order to find out what we as a group already knew about atomic energy and what we wanted to know about it.

The role of the teacher during this period was one of stimulating curiosity, of motivating, directing, and appraising; constantly alert to the students' interests, concerns, and opinions; the role of suggesting:

"There is a book in the library, called 'Secret' that gives an excellent discussion of that with vivid pictures and diagrams."

"We can find lots of information about that in 'Must Destruction be our Destiny' or from this pamphlet 'Where Will We Hide?' or from a variety of other sources."

"Yes, it is a fascinating book. Do you know anything about the author? He is a most interesting person. The story as to why he, from all journalists, was selected to report the Bikini Test will give you information about how authoritative his writings are."

"When was that particular information published? Why will we have to be very careful about checking the publication date of much that we read?"

"What facts do you have to support that opinion?"

"Several of the recent periodicals have contained information about the H-bomb. Do you know how you could find out which magazines these are?"

"Would you get that article and re-read it again carefully and see if that is what it really says?"

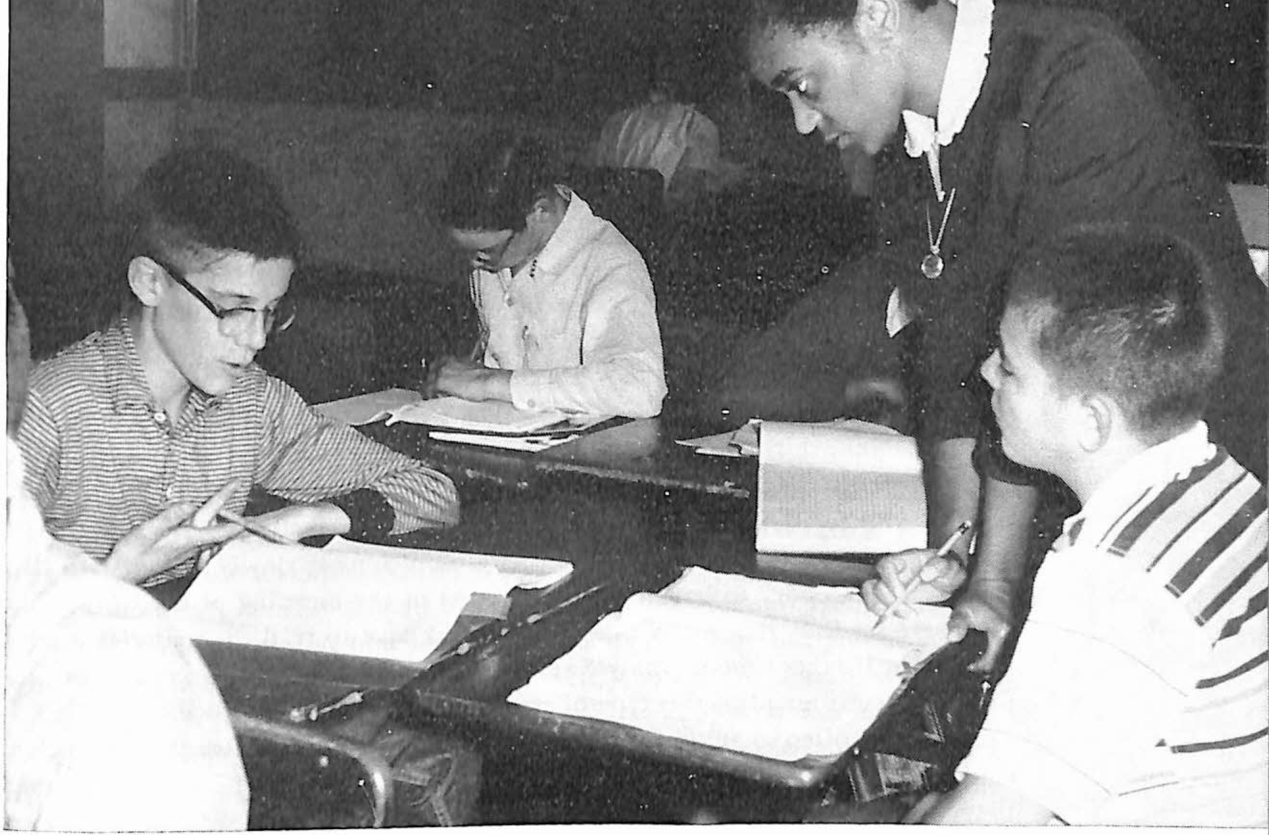
"Do you know how you could find out which books and magazines in the library have information about the possibility of atomic powered planes?"

"Many pamphlets have been published about atomic energy. Where can you find these in the library?"

We listed new words, names and places that we associated with atomic energy.

It was an exciting two hours. It was evident beyond doubt that the students were motivated and most certainly the teacher was enthusiastic about the prospects as to what could be done with such intense interests. At times, it was a problem to keep the students from all talking at once. There was some impatience and frustration because I wouldn't give them complete answers to their questions then—just enough to whet their curiosity more. It was often difficult to keep the exploration moving because the students wanted to stop and discuss the problems that were being suggested right then and there.

Topics brought up ranged from the A-Bomb and H-Bomb to stories of apprehension of spies, possible interplanetary travel, McCarthyism, and stories of fictional science.



For most of the students, this was the first experience in reading material for detailed technical information. They had to be shown that it was necessary to read this kind of information much more slowly and analytically. (Courtesy of University High School, University of Illinois)

We decided, as a class, that we needed to do more reading about atomic energy before we could plan definitely what we wanted to study about it. We also decided that as we read we would keep five lists: 1. New words; 2. names and places associated with atomic energy; 3. questions that we would like to have answered or more information about; 4. experiments and demonstrations that would help to explain atomic energy; 5. resources that we found.

We planned to spend the next several days exploring the resources of our library and the city libraries; examining magazines, books, and newspapers at home; looking for clues as to places and people that we might write to for information, and looking for pictures and articles to add to the bulletin board.

Each member of the class was asked to buy a copy of *Atomic Energy: Double Edged Sword of Science,* a resource text unit. This was the only common source of information used by every student.

THE PERIOD OF EXPLORATION AND SUPERVISED STUDY

It was evident to the group that they now needed help in using the library and its resources. The librarian was asked to come in and explain the general organization of the library, the location of materials, how the books were classified, the

card catalog, the use of the common reference books such as the *Readers' Guide to Periodical Literature,* the encyclopedias, almanacs, and the vertical file of pamphlet materials.

We also took time out during this exploration period to learn how to keep a bibliography, how to survey resource materials for future reference and how to use a book effectively. There was some resistance and objection to keeping a bibliography but much of this disappeared as the students found it a useful reference.

It was soon evident to me that they also needed help in how to read scientific and technical materials. For most of them, this was their first experience in reading material for detailed technical information. They had to be shown that it was necessary to read this kind of information much more slowly and analytically, that it was necessary to have definite concepts of the meaning of the words that they were reading, that many times they would have to read the material several times, that it takes time to analyze and understand scientific diagrams. Great improvement was noted in this type of reading as the unit progressed.

They were often so anxious to show me new finds and to discuss them that they couldn't wait until the class period but would stop me in the halls or wherever they saw me. Some even called me at home. The bulletin board was soon overflowing and they decided that the articles needed organization. Materials were rearranged under such headings as: people in atomic energy, science of the atom, the A-Bomb, the H-Bomb, Russia and the bomb, peacetime uses, and control.

During the first part of this exploratory period, as their curiosity was aroused, the students kept coming to me for the answers to their questions—"How did they set the bomb off?" etc. I cautiously refused to answer their questions and kept directing them to resource materials, being careful to follow up to see if they had found the answer to their question. For the first time during the year, many ignored the closing bell as they worked in the library or with materials in the room. The bell was often a signal to them that they could get together in groups and start discussing and arguing about what they were reading. Diagrams appeared on the board that they were using to explain things to each other. I remember particularly one evening when two of the school's "problem" boys stayed until five o'clock arguing over the merits of the different kinds of periodic tables.

PLANNING THE UNIT

A few became so interested in their investigations that they resented being disturbed when the group was called together again in order to make plans for the unit. When we met to check the results of our exploratory period, we listed the new words that they were finding on the board—energy, atom, proton, neutron, deuterium, tritium, cyclotron, reactor pile, isotope, radioactivity, energy orbit, fission, fusion, alpha ray, saturation weapon, total warfare—the list totaled more than eighty.

They were aghast at the list. "Do you mean we will have to learn all of those?" At the same time they were excited with anticipation. I suggested eliminating some as being unnecessary at this stage of investigation. I met opposition from someone to every deletion I tried to make. They were already aware that they needed definite understandings for critical readings and exact scientific knowledge. Most had experienced difficulty with the use of dictionary definitions.

How were we to build a glossary with definitions that had meaning to us? The librarian was called in again to help us with this problem. She introduced us to the different sources of definitions: glossaries of books of varying difficulty, the different kinds of dictionaries in the library. She pointed out to us how we could find the scientific definition in Webster's and in Funk and Wagnall, how we could work up from a simple glossary to the more technical definition, how the origin of the words sometimes helps our understanding, where we could find very new words, names of people and places, meanings of symbols and abbreviations.

Names associated with atomic science brought another list almost as long as the word list. We wanted to know more about these people. It was agreed that each person would be responsible for information about two. Again we needed help as to where we could find this type of information. The librarian aided us in getting acquainted with the different biographical references. Knowing how to look for biographical information helped us to find the material wanted in the most efficient way. To make sure that we used the variety of biographical references, we decided to make one of our two choices an early worker in the field and the second choice from the contemporary list.

Just as we finished our list of people that we associated with atomic energy, we were visited by the principal of the laboratory school in Hiroshima and his assistant. How embarrassed we were to realize a few days later that the name of Yukawa was missing from our list. Several worried that our visitors might think that we omitted it because of racial prejudice. Two decided to write them a letter explaining the omission.

The extreme interest of Mr. Torotaki and Mr. Masuda in what we were doing added to the enthusiasm of the class. Before they left they agreed to answer some of our questions about their experiences in Hiroshima if we would not ask them any questions about politics. The students listened and with bated breath to their explanations given in halting English and they were greatly impressed with their extreme interest in what we were doing and their repetition of "Of course there must be peace." We found the books which they sent to us about Hiroshima, books printed in Hiroshima for the American tourists, most interesting.

And then the listing of their questions. Eighty questions about the science of atomic energy alone! There was lots to be found out, lots to be learned! Would we have time to find answers to all of these questions? Upon examination it was found that many of the questions were closely related and could be combined. It was necessary for me to point out to them at this time that the understanding of some of the questions depended upon other knowledge which would have to

be gained first. It was agreed that I was to arrange the questions in a logical sequence. It was also seen that if we were to gain real understandings about the social, political, and moral implications that it would be necessary to master the fundamentals of the science of atomic energy first.

The following is a sample of the questions asked about the science of atomic energy. The questions have been left as they were phrased by the students.

1. What is energy?
2. How does energy differ from power?
3. Why do people want atomic energy, anyway?
4. Why is atomic energy better than other kinds of energy?
5. What is the atomic theory? Dalton's atomic theory?
6. How large are atoms? What do atoms look like? Of what are atoms composed?
7. What is the structure of the atom? What are elements, molecules, compounds?
8. What are electrons? Protons? Neutrons? Deutrons? Positrons? Mesons? Neutrinoes? What is an ultimate particle?
9. What is a nuclear charge?
10. What is an electron shell? Electron orbit? Energy orbit?
11. Why don't the electrons and protons within the nucleus repel each other?
12. Why aren't the electrons drawn into the nucleus?
13. If you can't see atoms, how do they know all this about them?
14. What is nuclear physics?
15. Are the atoms of a solid different from the atoms of a liquid or gas?
16. Just what is atomic energy? Nuclear energy?
17. What does E equals mc^2 mean?
18. What is the periodic chart? How is it organized?
19. What is radioactivity? A radioactive substance? Artificial radioactivity? Transmutation?
20. What elements are naturally radioactive? Why are only some elements radioactive? Where are radioactive materials found?
21. How do elements get to be radioactive? What is half-life?
22. What are isotopes? What are radioactive isotopes? Radioactive tracers? Tagged atoms?
23. What is an electroscope, spintharoscope, spectroscope, Crooke's tube, mass-spectroscope, Geiger counter, interpolator, cyclotron, betatron, Van de Graaf generator, synchrotron, Wilson cloud chamber, oscilloscope?
24. What are alpha, beta, gamma, and x-rays?
25. Why are radioactive materials dangerous?
26. What is atomic fission? Atomic fusion? Nuclear fission? Atom splitting?
27. What elements can be used for atom splitting? What is the difference between U-234, U-235, U-238?

28. Why was it necessary to separate the different kinds of uranium?
29. What is an atomic pile? Atomic reactor? Reactor pile?
30. What does it mean to denature fissionable materials?
31. What is a strategic material? What are the strategic materials necessary to manufacture atom bombs? Does the U.S. have all of these materials?
32. What is heavy water? Deuterium? Tritium?
33. Why do they say that solar energy is atomic energy?
34. What is meant by critical size?
35. How is an A-bomb set off? Where was the first A-bomb exploded? How many have been exploded and where?
36. How big is an A-bomb? How heavy? Cost? How much U-235 or plutonium?
37. What are the principal effects of an A-bomb? Are the effects of the under-water bombs different?
38. Were the bombs dropped on Nagasaki and Hiroshima the same?
39. Why were the effects of the bomb different in different parts of the bombed areas?
40. How long did the ground stay radioactive in Hiroshima and Nagasaki?
41. What did they find out by the Bikini and Eniwetok tests?
42. What is radiological warfare? Radioactive dust?
43. Where are the A-bomb plants in the United States? Why do they publish maps showing the location of the atomic energy plants and laboratories?
44. Can we keep the atomic bomb a secret?
45. Can the A-bomb itself be used for anything besides war?
46. Is there any known protection against atomic bombs?
47. Why can't we build defenses against A-bombs?
48. What is an H-bomb? A hydrogen-cobalt bomb? Why are they called fusion bombs? Why will H-bombs be more powerful? Has an H-bomb been built yet?
49. *Look* says one thing about the H-bomb and the book *Hell Bomb* says another. How do you know which one to believe?
50. Why don't we just forget about atomic energy, it has caused so much trouble?

Experiments were suggested to show energy changes in solution and in chemical change, to show molecular structure, the recovery of elements from compounds, the loss of the identity of elements in chemical union, the presence of ions, the presence of positive and negatively charged particles in matter, the nature of the electroscope, vacuum tubes, centrifugal force, how addition and subtraction of heat energy changes the state of matter, the effects of radioactive material on a Geiger counter, to demonstrate the chain reaction and the effect of bomb explosions.

Students volunteered to make models of atoms, molecules, a cyclotron, an atomic pile, the chain reaction.

Others planned to make diagrams and charts showing the separation of alpha, beta, and gamma rays; radium disintegration; the manufacture of plutonium; separation of U-235, possible structure of the A-bomb and H-bomb; plans of cities of the future; structure of the betatron, the cyclotron, Geiger counter, synchrotron, Van de Graaf generator; comparative difference in explosive power of conventional bombs and the A-bomb and H-bomb. Still others planned maps showing location of strategic materials, of atomic plants and laboratories, of distances from Moscow to strategic U.S. cities. Plans were made for a trip to the University of Illinois betatron.

While all kept a bibliography, one student kept an annotated bibliography.

NOTEBOOKS

I suggested at this time that they could make very interesting notebooks of the materials that they were collecting, and that the art teacher could help us design fascinating covers for them. A storm of protest went up: "We hate notebooks!" So I dropped the subject, but it was not long before they were offering to put their articles and pictures on the bulletin board, only if I would promise that they would get them back. Later a delegation came to me and asked me if I minded if they kept notebooks!! I again suggested the help of the art teacher.

His planning with them of their notebook covers was one of the most exciting hours of teaching I have ever observed. They discussed colors—hot, intense colors. Nancy agreed, "But I also think of blue, a very bright, intense blue." She searched the room with her eyes for an example. Finding none she decided "I think I'd call it electric blue. I think it's the fear of atomic energy that I associate it with." She found her blue for her notebook in a metallic paper and accented it with metallic red and orange.

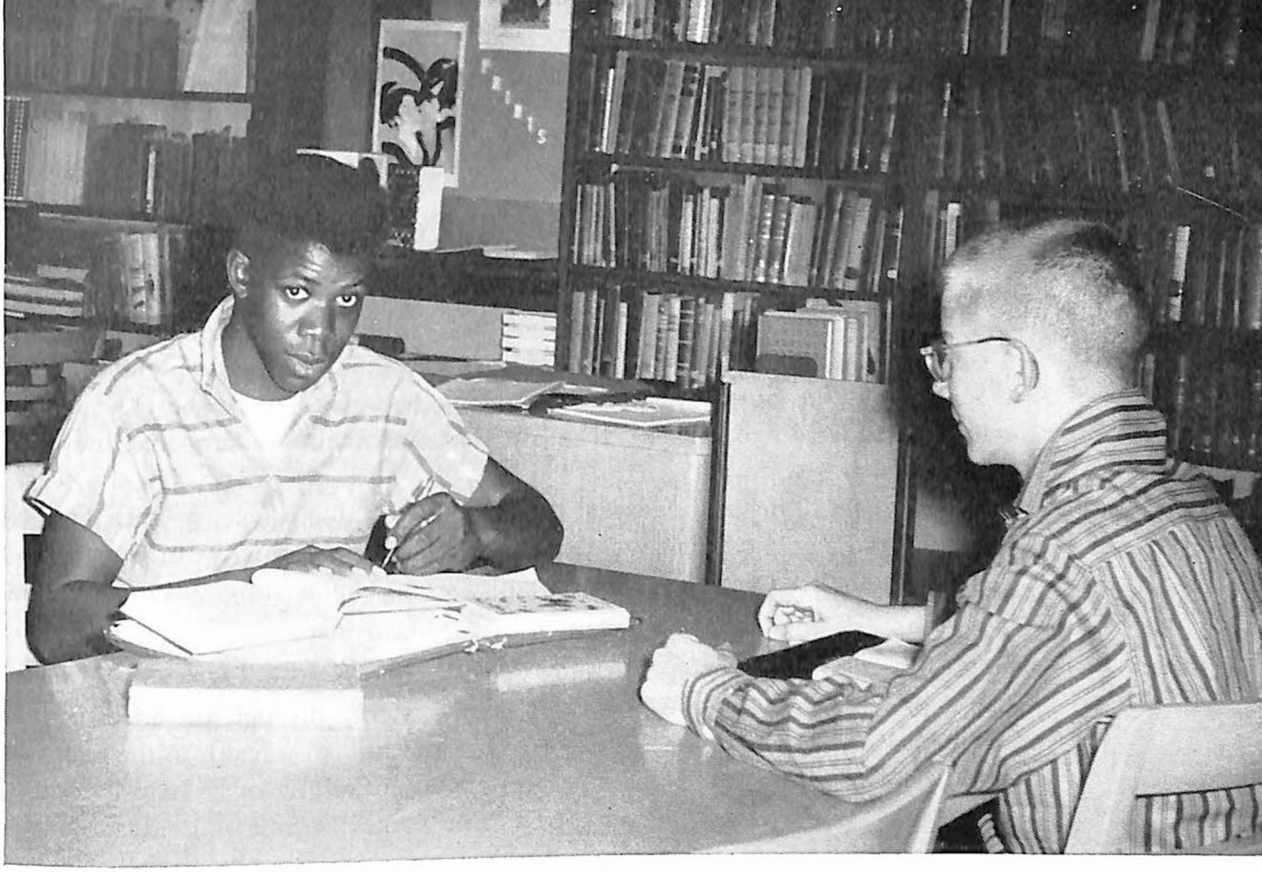
"And the lettering," suggested the art teacher as he printed "atomic energy" in thin italic letters. A storm of protest arose. "No, big, heavy letters; block busters!"

From the school's "problem boy": "They've got to be wider than high, three dimensional, run back deep."

Ideas for design came fast, atomic structural diagrams, sweeping arcs of electron orbits, radioactive rays, showers of electrons, chain reactions, the mushroom cloud, repeated patterns of E equals mc^2, and names of atomic scientists and fission symbols.

Names for their notebooks? "You and the Atom," "The Atom and I," "The Nucleus of Trouble"—a long slender bomb extending down through the heart of an atom. "The Challenge of Atomic Energy," "War or Peace and Prosperity."

The organization of the content represented their own concept of the subject. Many interpreted their ideas into design on division pages.



Library and supervised study and laboratory periods were scheduled to be interspersed with general class discussions. (Courtesy of University High School, University of Illinois)

WE STUDY THE SCIENCE OF ATOMIC ENERGY

Equipped with knowledge of the resources of the library, knowing what they wanted to find out, and with lots of ideas to express their knowledge as they found it, they were ready to go to work. Library and supervised study and laboratory periods were scheduled to be interspersed with general class discussions.

They found, at this time, that if they were going to exchange the information that they were finding they needed help in organizing and preparing their materials for presentation.

The reports about the people in atomic science were correlated with the study of atomic science so that the students had the necessary information to understand and appreciate the contributions of each of these people as they were given. For example, they had a concept of radioactivity before hearing of the work of Marie and Pierre Curie.

Early in the study of atomic science, there was a feeling on the part of several of being overwhelmed. This was evident in their remarks before and after class—exaggerations and ridiculous uses of the many new words that were confronting them--"Calm down or I'll fry you with my cyclotron."

There was some danger of the brighter students intimidating the slower ones with their knowledge to the point that they would be afraid to express themselves or afraid that their questions were so simple as to sound ridiculous to others.

I continually kept them aware of the fact that the only stupid question was the question that wasn't asked and that our goal was not to show off our knowledge but to help each other understand the fundamentals of this new discovery. My inability to answer some questions gave them courage. It was not long until we had built up a backlog of questions that they could not find answers to and that I could not answer or find suitable information about. We made plans to invite a member of the physics faculty to spend an hour with us at the close of our scientific study to help us with these problems—an hour I'm sure that they will all remember.

Besides developing a fundamental knowledge of atomic science, they learned the importance of checking the publication date, the authenticity of the article, to resolve conflicting information, to recognize sensational writing and propaganda.

HISTORY OF ATOMIC ENERGY

Their exploration of the history of atomic energy through the investigation of the people who made this history gave life and human warmth to the scientific facts they were studying. It became an exciting unfolding of a chain of events, as exciting as the chain reaction itself. The names became individuals and it was gratifying to see these scientists take their place on the students' list of heroes. One parent reported that her daughter had a large picture of Einstein on the wall of her room. There was a display of proud, almost personal, acquaintance with these people as their pictures appeared in the various movies that we saw. There was much excitement among the group when they read in the local papers that Dr. Urey was to visit the campus. They were as enthusiastic over seeing him as the bobby soxers are over the latest crooner.

They were able to make many satisfying and worthwhile inferences from the knowledge that they gained about the lives and works of these people:

- The importance and influence of a great teacher from their study of Rutherford and his many illustrious students—Becquerel and the Curies.
- The importance of pure research.
- The dependence of applied science and technological developments upon pure research.
- The relationship of one discovery to another.
- The internationalism of science.
- Our reliance in the past on European countries for advancement in basic science research.
- That science is an unrelenting search for the truth.
- That knowledge once accepted as fact must often change when exposed to the light of new discovery.
- That scientific discovery is not a monopoly of the United States.
- That many top flight scientists sought political refuge in the U.S. when their freedom to seek the truth was endangered.

The necessity to keep the supply of scientifically trained people flowing.

Why the knowledge of atomic energy cannot be kept secret.

The great importance of mathematics.

That scientists are human with families, interesting hobbies and personalities.

SOCIAL, POLITICAL, ECONOMIC, AND MORAL IMPLICATIONS OF ATOMIC ENERGY

At the beginning of the unit the class attitude toward this phase of atomic energy had ranged from apathy to a firm belief that they had no interest whatsoever in these problems. By the time we had finished our study of the science and history of atomic energy, they had done a great deal of reading, and often had brought many of these problems into their science discussions. Although their emphasis had been on material advantages of atomic energy they could not escape the implications of these. They began to become aware of the serious lag between our ability to develop new technological advances and to cope with their social impact. As they expressed their attitudes and opinions about these, areas of disagreement arose. As I questioned the basis of their opinions, they began to see that they did not have adequate information about them. Many of their early opinions showed traditional patterns of thinking, the repetition of well known clichés, the voicing of opinions overheard at home. I have tried to keep a record of many of these statements in their own words.

Wars are caused by a few people that want to make money and there's nothing we can do about it—why worry?

After all, we can't control the people in Washington that make the decisions.

We've got more modern conveniences now than we need—why more?

Why don't we go ahead and drop the bomb on Russia now while we have a chance and get it over with?

Why don't we just forget about atomic energy? The destruction it causes isn't worth the peacetime uses.

After all we can't protect the whole world.

We should have gone ahead and whipped Russia right after the war when we had the chance. We probably don't have a chance now since she's got A-bombs.

I don't see why we should get so excited about the A-bomb—after all there are worse things like bacteriological warfare.

Scientists have always found defenses.

We need a better intelligence department so that spies can't get our scientific secrets.

To help students find answers to questions which have definite answers is easy in comparison with preparing them to seek wise solutions to problems with no

set solution and to problems which require that their solutions change as the situations change.

Here the problem was not as simple as just finding the answers. Here the teacher's role was to help the students identify and clarify their problems. It was not as easy for them to identify them in this area. It was necessary to lead them to see that free discussion alone would not bring sound unbiased solutions, free from emotional desire, wishful thinking and ambition; that their free discussions had to be preceded by much free inquiry; that their free inquiring would not be easy because they would find many conflicting opinions. They had to be given help in how to collect conflicting information, how to analyze and evaluate their information, how to sift their materials critically and separate the sensational, the irresponsible and the false from authentic information. Their knowledge of the history of the development of atomic energy helped them to recognize many sound authorities but now they had to become acquainted with authorities outside the field of science. They needed help in how to draw conclusions from their sifted facts.

But more important still, I think that it was essential to lead them to see that many of their solutions arrived at in this manner would necessarily have to be tentative solutions based on current information, solutions that would necessarily be subject to change as new evidence is gained and as situations change.

During our investigation of the implications of atomic energy we kept two quotations on the board before us:

"Education is preparing to accept responsibility in such a way that we become a valuable member of society."

"I know no safe depository of the ultimate powers of society but the people themselves, and if we think them not enlightened enough to exercise their control with a wholesome discretion, the remedy is not to take it from them but to inform their discretion by education" by Thomas Jefferson. The students were helped to develop the attitude that we need not wait to see what happens but that with a clear understanding of a problem as a basis we can help determine what happens. Efforts were made to develop with them concrete ways to determine what happens to society.

Their problems in this area demanded the development of group procedures: the different kinds and purposes of free discussion, group planning, the panel discussion, round table discussion and methods of working together as total groups and in small groups.

Their interests fell into four areas: the bomb and its effects; peacetime uses of atomic energy for power plants, engines, radioisotopes as a research tool in medicine, biology, agriculture, and industry; the national and international control of atomic energy; and political implications.

Sample questions and problems which grew out of their reading and discussions were:

1. Why can't we outlaw atomic bombs?
2. How can cities be replanned to make them less vulnerable to A-bomb attacks? What is a ribbon city?
3. Was the U.S. wrong in dropping the bomb on Hiroshima and Nagasaki?
4. What is atomic fuel? How will the cost of atomic fuel compare with the cost of other fuels?
5. What changes in our ways of living are likely to develop with the peacetime uses of atomic energy?
6. What is photosynthesis? What is "ocean farming?"
7. What are the problems in the control of atomic energy?
8. What is the difference between the U.S.A.E.C. and the U.N.A.E.C.?
9. Why do some people think that it is dangerous for the Military to have control of atomic energy?
10. What are the arguments for and against World Government? What would a world government be like? Are there other proposals for the solution to world cooperation?
11. What is a world police force?
12. What was the Lilienthal-Acheson proposal? The Baruch proposal?
13. How may our solutions for the control of atomic energy endanger or alter our democracy?
14. Why do some scientists object to working on atomic energy research?
15. Should private enterprise have greater participation in the development of atomic energy?
16. How will the enforced secrecy of atomic energy research affect scientific progress in this field?
17. What do they mean by "The enforced secrecy of atomic research may kill the goose that laid the golden egg?"
18. What are the ways that we can check on the actions of our representatives?

It was most encouraging to see the group grow in ability to attack problems of this sort through acquiring information, weighing it objectively and reaching conclusions with tolerance for the viewpoints of others.

TESTING AND EVALUATING RESULTS

Testing and evaluating were done by means of: objective testing of the students' knowledge of atomic energy; objective testing of library knowledge; subjective testing of their knowledge of the social, political, and moral implications of atomic energy; testing their ability to organize their information of the entire field through the preparation of papers such as "What I Have Learned in Atomic Energy" and organization of the content of their notebooks; evaluation of oral reports, demonstrations, group participation, projects, and written work;

analysis of bibliographies for content and form; anecdotal records of individual and group reactions; a student opinionnaire given at the end of the year.

I have felt from all of these that the interest was such that every student in both groups, with the exception of one, worked up to capacity; that a satisfactory knowledge of facts was gained by all; that there was more than the usual amount of creative expression of what they were learning; that every student laid a good foundation for continued growth in library skills, in notebook skills, in planning skills, and showed favorable growth in both written and oral communication skills; that their reading interests were broadened greatly and that most made such improvement in their ability to read technical, scientific information, diagrams, and pictures accurately; that they had learned to read much more critically and analytically.

Standardized test data based upon the entire year's work showed gains of as much as 50 percentiles in the lower range and of as much as 10 percentiles in the higher ranges of percentiles in library study skills. Gains in reading ability ranged from .3 months at the higher reading levels to as much as three years growth for some of these in the lower reading levels. Several showed loss in reading rate but a comparable gain in accuracy.

On the Student Opinionnaire of the course, the Atomic Energy Unit was ranked as one of their favorite units and as one of the units most valuable to them.

The first group was able to give a creditable one hour group discussion of their experiences in this unit for a Summer Education Workshop with only two preparatory meetings consisting of a thirty minute planning period and a one hour practice period.

Free discussions initiated by individuals when they come in to show me new articles that they found not only show a continued interest but a retention of rather detailed factual knowledge.

EVIDENCE OF STUDENT INTEREST

There was much evidence that student interest went beyond the classroom and continued after the close of the unit. One parent reported, "I bring these kids to school in the morning and I've never heard such conversations—about 'isotropes' and words I've never heard of."

Two students waiting for home rides stopped me, "Mrs. Lindsey, we've been arguing about whether Champaign-Urbana is a strategic area."

During a holiday vacation a student called me, "Mrs. Lindsey, I hate to bother you, but my little brother (age nine) and I have been having a terrible argument. Didn't you tell us that we would probably never be able to see atoms? My brother has an article that says that they have made pictures of atoms with a proton microscope." She later brought a letter headed, "Massachusetts Institute of Technology—Dear Mike:" Mike had written to the author and had received a page long answer verifying the information that he had found and a statement: "Your

doubt of what may sound to be an incredible statement shows the characteristics of the making of a good scientist."

The news of the possibility of a hydrogen bomb broke two months after we had completed the first unit. One of the students came in with three newspaper clippings and laid them out on my desk, "Look Mrs. Lindsey, Dr. ——— has changed his mind three times in one week about what we ought to do about the hydrogen bomb."

Last year's group checked constantly on the work of this year's group and some asked to stay after school and see again the movies we were using. Several have continued their notebooks, one of which received the outstanding award in the Junior High School Division of the Illinois Academy of Science Exhibit. The author of this notebook was considered by many of the faculty to be the school's number one behavior problem.

There were many evidences of change in opinion and social attitudes about atomic energy. There were some interesting differences in the opinions and attitudes of the two groups—differences influenced by the change in the more current articles that the latter group was reading, changes associated with a year of national and international change. They represented changes from the general feeling that war is remote, to the opinion that war is most imminent; from much confidence in the United Nations to quavering confidence in the United Nations; from hope for the possibility of world federation to skepticism of its probability; from a feeling of the superiority of the United States and little fear of Russia to doubt of the strength of the United States and great fear of the immensity and power of Russia; from some tolerance of Russia's attitudes and actions to no tolerance; from a feeling of security due to the possession of the A-bomb, an ultimate decisive weapon, to one of little security—"The A-bomb is not all it was cracked up to be;" from the seeking of protection through wishful thinking that "surely there must be a possible defense if we just make the U.S. strong enough," to less feeling of security based on our geographical location in the midwest; more interest in the possible implications of the problems of control of atomic energy to our democracy, with interest in its relation to free enterprise, personal freedoms, academic freedoms and freedom of scientific research; change in the emphasis on seeking protection by going underground to complete rejection of this idea, replacing it by discussions of decentralization of cities and industries; and greater interest in plans for civilian defense.

There was much evidence that both groups were growing in problem solving techniques: increased willingness to check evidence on both sides of a question, of critical reading, of comparison of evidences, of recognition of authoritative resources and of sensational writing and propaganda. Above all, I feel that there was a marked increase in their sense of their responsibility as citizens of this nation and of the world.

NOTE: *The preceding account by Mrs. Lindsey described a unit on atomic energy as seen by the teacher. The following consists of separate*

statements written by thirteen young people who were members of the Freshman Problems class and who studied the unit on atomic energy that Mrs. Lindsey has described. These students are from the first group which studied the unit.

A year after their study of atomic energy, these students were asked to write brief statements on how they felt about their unit. Did they enjoy it? What did they not like about it? Had it been of any benefit to them? More was not suggested for we did not want to put words in their mouths. We explained merely that teachers were interested in knowing what students thought, told them how their statements were to be used, and indicated that they could sign them or submit them anonymously.

The statements that appear here were prepared by the students on an individual basis at the time they were first called together. They did not have the opportunity to review their study or to have their opinions prejudiced through discussion with others. The statements do not represent the entire group as some were absent from school at the time they were prepared, two of the original group were no longer at the University High School, and three students did not want to prepare statements, pleading lack of time.

The statements are unedited and appear just as the students submitted them, errors and all. Here is what one group of young people have to say about a core unit in atomic energy. It should help the reader in appraising the merits of the unit.—R.W.B.

WE STUDIED ATOMIC ENERGY

Although not perfect, this course was one of the most interesting and enlightening classes I have ever taken. The interest of the class was so great that hardly an evening went by but what several students stayed until four or five o'clock discussing some of the facts and issues raised in class.

Besides the factual knowledge it provided, this class was useful to me in broadening my interest. At the beginning of the unit I think the rest of the class agreed with me in feeling that the scientific viewpoint was the only phase worth studying. As time wore on, and we actually studied the social, military, moral, and other aspects, we very definitely began to appreciate these elements too. While I still think the science is the most important factor, I don't by any means feel that it's the only one.

In our studying we ran across several statements to the effect that educating the public as to atomic energy is pitifully neglected. Because of this and the interest of the subject, I think it's too bad that all the children in all the schools can't be exposed to a course like this.

STUDENT A

Since we began our atomic energy unit by discussing what we already knew about the subject, and by raising questions, all of us, no matter how little we knew about it, discovered the scope of the field we were to learn about. After several days of explora-

tion, we pooled our bits of information—and our many queries—into a logical outline for the course.

First, we explored the science of atomic energy. This proved to be a little confusing until we became acquainted with the atomic "jargon" and the men behind it, but then the protons and cyclotrons and geiger counters that had been just words took on new meaning.

When we came to discussions of the atom and its effect and uses for the world, there was a good deal of disagreement. Sometimes we got off the original subject, but in the end those discussions proved most stimulating. We increased our understanding of the problems of controlling the atom, and the United Nations' role in this.

Near the end of the unit, the organization of our notebooks consumed a good deal of time, and, I think, proved worthwhile. They summed up our learning in the unit, and gave us a chance to present our own personal outlook on the atom and its place in our world.

Now that I look back on the unit, I think that it helped me to realize the possibilities of the atom in war, and awakened me to the limitless potentialities of the atom in helping man to increased health, safety, and prosperity. It made me aware of our responsibility to the people of the future in the ways we use this atomic energy. STUDENT B

I feel that in choosing the Freshman Problems Atomic Energy unit, I was very lucky. I had my reasons for choosing this unit, true, but there were two other units I might have taken at the time. However, I believe that I got more out of the atomic energy unit than I could have from both of the other two units put together. I believe that it was by far the most profitable unit in the whole course; certainly it was the most interesting.

Atomic energy in the world today is one of the most dreaded and most marveled at discoveries of science, and yet there are many people that do not know a thing about it. Or maybe they do know something about the subject, but not enough to do any intelligent thinking on the subject—just enough to be afraid of the whole topic. I believe that education on this topic is badly needed; certainly atomic energy is not to be regarded with an air of suspicion, for many wonderful things can be done with the use of atoms. This course brought to light many of the things that I had been wondering about and completely enlightened the whole field of atomic energy to me. If the world in general is going to get along with atomic energy on even terms, the public should be enlightened. And what better enlightenment could there be than an education on this topic at school?

STUDENT C

The choices were, Atomic Energy, Movies in American Life, and The Air Age. My first impulse was to take the movie unit. Atomic energy seemed much too complicated. Most of my friends had decided on the movies and I thought that would be pretty interesting. Then I started to think. I'd been hearing a lot about atomic energy lately. What are isotopes? What makes the A-Bomb so much more powerful than any other bomb? What would happen if we became engaged in atomic warfare? These were some of the questions that popped into my mind. My mind was made up. I changed the check mark to the Atomic Energy column. That is one decision I don't think I'll ever regret.

From the very beginning I knew I was going to enjoy it. At first though, my head was swimming with all the new names, terms and vocabulary that I'd never heard before.

After about three weeks of research, diagrams and class discussion, light began to dawn and at the end of the unit, I was pretty pleased with myself.

Now when I read articles in newspapers and magazines I no longer have so much trouble understanding the scientific terms and I know what some of the famous names are famous for. I also realize what kind of an effect the A-Bomb would have on people if ever used steadily in war, but on the other hand, how wonderfully it could serve man in peace-time.

I can truthfully say that I enjoyed taking Atomic Energy and, as I said before, I don't think I'll ever regret my choice.

STUDENT D

I think that the unit we had last year on Atomic Energy was very interesting!

To begin with before we started the unit we had our choice of three subjects. If you did not want to take Atomic Energy, you could take one of the other two. This was good for two reasons. First it cut down the size of the group, and secondly, everybody that was in it had chosen it and was interested in it.

Also at the beginning we chose just what the group wanted to study.

There were movies and demonstrations throughout the unit which helped a great deal.

We not only studied what it could do in war but its peacetime uses also. We studied the elements and atoms and how the bomb worked.

Another interesting part was about some of the people that were connected with the atom bomb.

On the whole I think that the unit was very interesting and very worthwhile. Also, I would like to say that if it were not for our teacher, Mrs. Lindsey, we would not have gotten as much out of it. Her interest in the subject had a great deal of influence on the group.

STUDENT E

I thought that the course was largely beneficial. Although when I started the course I did not expect much out of it. I now feel that I did get a lot out of it. When I entered the unit, I knew nothing of atomic energy, or atoms of any size, shape or form. I now know a lot more than I did about atomic energy. In the Junior Academy of Science in Illinois, I won an outstanding award for a note-book I wrote on the subject. STUDENT F

I thought that the unit on Atomic Energy that we had last year in Freshman Problems was very interesting. In the first place I think it is a very interesting subject and I felt that since not too much is known about it, and most of what is known is very difficult, I had more of a chance to explore the topic and see what I liked best and what was the most difficult, etc. I found that the part I liked best was about the atomic periodic table and the make-up of the atom and the other elements.

It also wakes you up to see what the atom bomb is able to do and also what could be done with it in peace time. I didn't enjoy the part about the bomb too much, but I did find lots of information on it that I didn't know before. I also read the book "Hiroshima" which I found very interesting.

After taking the course, I pay lots more attention to everything I see and hear about the atom.

I know there are some things about that course that will stick with me forever. I can say that I really enjoyed the course even though that was just a starter and I have lots more to learn.

STUDENT G

I studied Atomic Energy in my Freshman year in high school when I was fourteen. There was so much material being published at that time on atomic energy and the atomic bomb that it greatly aroused my interest. The main trouble I had in understanding this material was with the terms it used. Even with the help of the dictionary, I could not comprehend the material. I also wanted to know more about atomic energy.

The unit we had on atomic energy explained the terms and elaborated on them. It gave us the basic information we needed to understand atomic energy. The way in which this was accomplished was interesting and plain to understand. The material was presented in individual reports, group discussions, and lectures by the teacher.

I was not too interested in the making of the notebooks which we did at the end of the unit because I thought that the material I learned during the course was the information I would remember and be able to refer to. STUDENT H

In Freshman Problems we were offered several choices of subjects. The particular unit I chose was a unit on atomic energy. I had read some material that concerned atomic energy

before I took this course. This combined with the steady stream of articles in the local newspapers, aroused my interest. I was also quite interested in the effects of atomic radiation on humans. To have a number of other questions answered I took the course. It proved very interesting due to the clear organization of the material presented and the teacher who instructed us.

After taking the course, I was able to understand more clearly the material in magazines and newspapers which dealt with atomic conflicts. Every student should be offered a chance to take such a course as I did. I believe if I had another opportunity I would take the course over again.

STUDENT I

I thought that on the whole the Atomic Energy course was pretty good but I think that the scientific parts (structure of the atom, etc.) should be completely separated from the non-scientific material (city defenses against atomic attack, etc.) so that we could go more into detail. The course was not particularly hard and I think we could go into more detail than we did even if it involved lengthening the course.

STUDENT J

I was thirteen years old, a Freshman, when I studied atomic energy. I decided to go into that group because I knew so little about it and I wanted to know what it was all about. We studied the science of atomic energy and the effects and possible uses of it in wartime and peacetime.

I don't think the chemicals elements and that stuff was very worthwhile because we studied it a year ago and I already have forgotten most of it. But it is necessary to know the vocabulary and the essential facts on how the atom works, etc. I liked learning about the effects and potentialities of the atom.

Now when I read magazine and newspaper articles, I understand them unless they're very technical. I feel that it was very worthwhile studying atomic energy since it is so important and our generation will be the ones to decide how we're going to use it—for our betterment or our destruction. I think it is necessary for everybody to learn about it.

STUDENT K

I enjoyed the unit very much, but there were several places where I think it could have been improved. We went into the science of it but not very thoroughly. One of the most interesting parts of the unit was when we made and developed atomic energy notebooks. I obtained from many articles and information which I sent for valuable and clear explanations of problems which I had not understood before I studied atomic energy. I think we had a very good teacher and she did a very good job in helping

to develop the unit with us so we could study what we were most interested in.

STUDENT L

I think that the course was well taught although quite difficult. I didn't learn much myself because I wasn't interested enough and didn't study enough which is my own fault. However now I wish that I had the chance to take it over. Some of it I found interesting but that wasn't the part that the others wanted to study most.

Nearly everybody studied the scientific part of Atomic Energy the most and my brain just doesn't work that way. I was more interested in the uses of it in War and Peace time.

The course did help me in using the library which I was not very good in before I took Atomic Energy. We had to use a lot of references and lots of different books for information. I believe this was one of the primary purposes and it certainly helped me a lot.

From my own point of view I didn't enjoy the course very much but for people really interested in it I would recommend it highly.

STUDENT M

13

A MENTAL HEALTH UNIT THAT MADE A DIFFERENCE

This present chapter is an account of how a biology teacher developed a unit on mental health and incorporated it in his instructional program.[1] Charles W. Mohler, the author, teaches biology at Bloomington High School, Bloomington, Illinois. The unit which he describes in the following pages was based upon considerable preplanning, including the development of a resource unit which specified his objectives and detailed a wide variety of possible learning experiences, teaching materials, and basic reference works. Space does not permit reporting on the resource unit as such. But the reader will find that the construction of a resource unit is an almost necessary stage in the development of a sound teaching unit that deals functionally with such areas as atomic energy, racial prejudice, mental health, conservation, and the wide variety of other possible topics which employ science content and experiences for the purpose of clarifying and resolving living problems. The reader is encouraged to study Chapter 7 in connection with his study of this chapter and the others in this section of the book.

HOW A BIOLOGY TEACHER TAUGHT A FUNCTIONAL UNIT

It is increasingly apparent that our schools are becoming aware of the importance of the problem of mental adjustment in regard to high school students. It

[1] This chapter is slightly adapted from "High School Biology and Mental Hygiene," an article by Charles W. Mohler which appeared in the December, 1950, issue of *School Science and Mathematics*. Reprinted by permission.

has been our observation that the subject of mental hygiene is best included in a course where an understanding of human behavior comes in a natural sequence as part of the development of the individual; moreover, *mental growth, physical growth, and emotional growth are inseparable* and should be integrated into the subject field in which these three aspects of the personality could be taught most logically. It has been our conviction that this could be done in the now existing courses of most schools. Take, for example, biology. Of course mental adjustment of pupils is not a problem for the biology teacher only but for every teacher regardless of the subject which is taught. Most individuals go through a normal sequence of development, both physiologically and mentally, and, therefore, an understanding of these processes would be an excellent way to introduce an elementary study of mental hygiene.

Basically mental hygiene and biology are related and overlapping in certain areas. If we consider that biology is the study of living organisms and mental hygiene is the adaptation of human organisms to their environment, then the basic knowledge of biology would lead to a better understanding of mental hygiene. The gradual processes involved in the evolution of various organ systems of animals, especially in relation to the increasing complexity of their nervous systems, give the students a comprehension of how man's complicated behavior probably arose. The studying of actual responses in lower organisms is important in that it gives the students an insight into the more complex behavior patterns of man. Besides giving the students a perception of behavior, it allows them to formulate their own ideas of human behavior at their respective level of development. The whole idea of mental hygiene is new to most students and by correlating this material to something already learned the study of mental health would become more real and interesting. For example, if a student can see how an amoeba adapts itself to its environment by means of differing responses in receiving various types of stimuli, then this comparative type of teaching could be used in several animal phyla to portray the increasingly complicated types of responses shown in higher organisms. Moreover, in those schools where there is no physiology or psychology in the curriculum, health is an important phase of any biology course. Human health, in its physiological aspects, is adequately covered in most biology courses; our most recent textbooks give ample evidence of this fact. But what about the question of mental health?

Most recent textbooks in biology are almost devoid of material on mental health. To be sure, most biology texts abound in materials on ecology, but the important problem seems to be how to relate this material to the experiences of the student in terms of mental hygiene. The idea of relating animal and plant adaptation to human adaptation is not a new idea but it certainly could be of more practical use in mental hygiene. There have been many studies made which show that facts by themselves are of little value to the student, and unless there is some direct use made of these facts, there is no functional learning. It is our contention that the student correlate biological facts with psychological facts.

Thus two goals are reached at the same time, (1) a knowledge of biology, and (2) a knowledge of mental hygiene. In other words, the student uses biological facts previously learned to understand human behavior.

The sophomore year of high school would seem to be the best time to give the student some insight into his particular problems in terms of his age group, because they are of major importance to the student at this time. A good place for the introduction of mental hygiene would be after a study of the physiology and anatomy of the nervous system and sense organs. It would be a natural step from a study of the nervous system to individual adjustment in terms of the nervous system. Of course, in all discussions of this type, one can not omit the socio-psychobiological implications; in fact, they should be discussed simultaneously with the psychobiological mechanisms. When insects are studied, the individual insect is studied first to acquire some general facts, then later these learnings can be used to interpret facts regarding other insects and to formulate some ideas about insect behavior in terms of the individual responses within the group. In other words, mental hygiene has to be simplified so that the student can understand some of his own immediate problems if the objectives are to be successful. Heretofore, it has been apparent that the physiology and anatomy of the individual has been stressed without giving along with these an understanding of the mental and emotional growth of the individual in his environment.

In Theodore Reik's book, *Listening with the Third Ear,* he says, "Schools now teach boys and girls anatomy and biology, but no one teaches them that the psychology of the sexes is different, that men and women go differently about the business of living and loving. The images and thoughts which the adolescent boy and girl connect with the words are not the same."*

Dr. Milton Rosenbaum of the University of Cincinnati on his twelve point program for mental hygiene says in his sixth point, "In the schools: Raise even higher the standards for teachers, with emphasis on the emotional capacity of the teacher to handle children and on the teacher's training in human behavior and group psychology. At the same time, teach mental hygiene courses to the youngsters.†

Some have said that mental hygiene is a problem for the guidance director or counselor. It is difficult to agree with this statement because all students at the adolescent age need the assurance and understanding that others have the same mental difficulties as they themselves have. Furthermore, if in discussion of these difficulties the reasons are explained in terms of the individual's experience, the students will be equipped to make better adjustments to their life situations in the future. At the sophomore level is the best time to establish self-confidence and lessen anxiety by a group method of study in mental hygiene.

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* Theodore Reik, *Listening with the Third Ear* (New York: Farrar, Straus and Cudahy, Inc., 1949), p. 92.

† Margaret Shields, "We Can Prevent Mental Illness," *Hygeia*, 27:866 (December), 1949.

Such an experimental unit on mental hygiene has been tried in our school, incorporated in the study of biology. One of the reasons for including this unit in our curriculum has been mentioned previously. It has been found over a two year period of individual consultations with every student in biology that many problems face our students without our being aware of them. Questions dealing with emotions and emotional tensions were clearly evident in a large number of the students' answers. That high school students had various problems which were not expressed and were ill-defined was very evident from talking to them. Emotional problems were revealed when such questions were asked as: "Do you worry over school work?" "Are you nervous?" "Do you get angry easily?" Do you feel restless?" and "Do you feel like exploding sometimes?" These questions and others elicited quite a different reaction than a question like: "Do you have any problems?" This direct and general type of question failed to elicit any response from a student because he was not consciously aware of his many anxieties and emotional tensions. On the other hand, some answers revealed that the students were aware of their specific problems, and others in the group simply did not understand the reasons for their feelings. The more bizarre the student's personality, that is, the more a student failed to conform to the mores of the group, the more difficult it was to get him to admit that he had any problems. In these cases it seemed that the student was definitely trying to "cover up" or protect his self-esteem.

During the year two sets of questionnaires were given to the students relating to psychobiological problems of adolescents. These questionnaires were compiled from various psychological and educational sources which were concerned with the ill-defined problems of youth. Through use of these questionnaires and of personal interviews the important problems of the students became apparent and were helpful in determining what the students wanted most to know and the best way to help solve their problems. Around these needs and desires of the students was built an experimental unit on mental hygiene.

The recurring teaching problems most often confronted were relating materials studied to the students' experience and avoiding theoretical psychology and trying to limit the materials to the problems which were of greatest interest to the students. It is to be supposed that these problems were not completely or absolutely solved, but evidence from the interest shown by the students for these topics gave ample proof that at least the students acquired some information about human behavior.

A pre-test was given to determine what the students already knew and what things should be stressed in regard to a study of mental health.

The following report on the mental hygiene unit includes three major divisions:

1. Individual reports
2. Laboratory exercises
3. Understanding yourself

PART I: INDIVIDUAL REPORTS AND BACKGROUND

The first part of the unit was made up principally of individual investigations and oral reports by the group. This part of the unit allowed the student to do some exploratory reading and investigating by himself under the teacher's direction. There was a preliminary discussion of twenty-three topics in order to help the students make a selection based on their needs. Each of these twenty-three topics was written on the blackboard and explained briefly by the teacher, followed by a question period under the teacher's guidance. After reading and exploring various materials, both in and out of the classroom, each student selected five topics from this list of twenty-three, indicating those he would like to study individually in order of his preference. An analysis of the twenty-three topics chosen by the students revealed that seven of the topics were preferred over all others. These seven topics revealed that adolescents were interested in psycho-social problems. The seven topics are as follows:

1. Culture and Personality
2. Behavior of Boys and Girls
3. Parent and Child Relationships
4. Adolescent Psychology
5. Who Is Normal?
6. Age for Marriage
7. Marriage

The students were told to make their first choice, second choice, et cetera, on the basis that, if they could not get their first choice, then perhaps they would be given their second choice, and so on. In this way each one of the students received a topic of real meaning to him and at the same time the teacher could actually manipulate the topics which his observation indicated would be best suited for the individual. Each student's ability was taken into account when he selected a particular topic, especially as to the complexity of the topic. When it was observed that a student had a particular problem, he was given the topic to report on which the teacher thought would help him the most in understanding and correcting his difficulty. The greatest student need seemed to be that of studying and *clarifying* these existing problems. Allowing the students to make their own choices not only provided a direct approach to the problems presumably most troublesome to them, but, in addition, it also served admirably as a device to create interest in the work.

It was evident that the students were interested in things involved in their immediate experiences such as culture and personality, normality, adolescent psychology, age for marriage and parent-and-child relationships. It is interesting to note that boys and girls at the sophomore level are between two stages of development in so far as social concepts are concerned. On the one hand, they are still quite concerned with themselves and, on the other hand, they are beginning to see that the other person may have some effect on their particular

psychological make-up. The process of socialization of adolescents is clearly at work at this age level, affecting most of the class; however, there cannot be a definite line drawn for each individual, inasmuch as this process of socialization takes place within the individual student.

The basic reports were prepared from carefully selected psychological and psychiatric books in which definite page assignments were given to be read and notes taken. After the student had read the material and was given further help and guidance from the teacher, he had a general idea of the over-all problems in relation to his particular problem. The student was made to feel that he was to be the authority on the problem of his choice and the other members of the class would look to him for specific answers in regard to their individual problems in his field of study. In this way it was felt that each student could present soundly based views on adolescent problems and still cover a relatively large amount of material. Each student was given several questions that he was to answer for the benefit of the class. Every member of the class had a mimeographed booklet containing the name of each report, the questions asked, and space to write the answers. By using this method the potential inattentiveness of some of the students was eliminated during the time when the reports were being given. The students, after making a basic study of their material, and having an individual consultation with the teacher, were encouraged to gather data from magazines, papers, books, the radio, movies and any other source of material which would help to amplify their reports. As the need arose, students were allowed to go to the library during class hour, others in small groups discussed common problems and exchanged ideas, and the teacher stood by ready to direct or help individuals during this period of activity.

At this point several students suggested putting magazine and newspaper articles and pictures on the bulletin board so that all classes could benefit from the items and pool their information. Various headings and placement of the respective materials were discussed and decided by the group. The bulletin board became the meeting place of the students before class started. No one was told to read the bulletin board, but the students themselves enthusiastically approved the materials so that they created in others an interest and a desire to read the materials.

The student reports were arranged in order with two considerations in mind: first, to accomplish gradual development of concepts from simple to complex and second, to bring into use additional audiovisual materials which would help to clarify and make less monotonous the giving of oral reports. For example, the first report started with the nervous system and its functions, and was followed by another report on the relationships of the nervous system to human behavior. In this way, by a gradual approach, the materials could be introduced and assimilated in a logical, progressive manner.

After the first report was given, the matter of public speaking was brought up and discussed by the class. So time was taken to decide on the proper manner

in which a person should give a report that would be acceptable to the group.

After each individual's oral report was completed, there were many problems to be discussed. Some topics elicited more discussion than others, but whether this was due to the very nature of the topic or to the personality of the student giving the report was not definitely known. It was surprising to notice that the students were very much interested in such problems as old age, divorce, and the family. It was not long before the students showed evidence of being somewhat aware of the psychological mechanisms of interpersonal situations at work and, on several occasions, demonstrated their ability to handle individual problems occurring in the classroom by the method of group discussion and analysis with the aid of the teacher's guidance and direction.

Another interesting aspect of this experimental unit was that the three classes being used were taught by three different people. There were two student teachers and the supervising teacher. Every Monday morning the plan for the week was outlined and then each teacher taught the material, using his own methods. A pre-test and an evaluation test of this unit were given by the teachers. The results of these tests will be deferred until the latter part of the discussion.

In between the oral reports other activities were introduced and used such as, discussion of subject matter, bulletin board work, and when appropriate, other audiovisual aids. Especially helpful was a series of five records which were obtained from the United States Government Department of Education. These recordings covered various aspects of mental hygiene, acquainting the students with common types of mental disorders and how to deal with them, and marriage problems based on a comparison of marriages of the last generation with those of the present generation. The records had the advantage of giving several case histories in story form which the students were keenly interested in analyzing and criticizing.

Another type of audiovisual material used with the reports was motion pictures. There were six movies shown covering the various aspects of mental hygiene. The first three films were concerned with an understanding of the processes involved in mental hygiene. These films dealt with tropisms, insect behavior, instincts, reflex actions, and higher types of human behavior. The last three films were concerned with mental mechanisms. The students enjoyed the films and data on the films were recorded in their booklet on the pages allotted to the pictures. Some additional films will be added next year to help clarify some rather difficult points in mental health.

Another source referred to between reports was the book *Human Relations in the Classroom*.* Lessons on good personality traits, making quick decisions, forming a philosophy of life and tolerance were used to demonstrate in a practical way what we were trying to accomplish. These lessons fitted into our program

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* Edmund H. Bullis and Emily E. O'Malley, *Human Relations in the Classroom* (Wilmington, Del.: Delaware State Society for Mental Hygiene, 1947), Vol. 1.

admirably because of their simplicity and their unique method of getting the students to participate, and they also gave the students something practical in the way of analyzing a psychological situation in terms of students' experience. Furthermore, these human relation lessons helped the students to discuss their own difficulties more easily. This was done by presenting a story, then discussing the story, and finally asking the students if they ever had a similar problem. The use of this device was probably one of the most desirable ways to make a transition from an objective situation to a subjective type of situation. Eventually this type of discussion gave the students some insight into their own personality, which was one of the main objectives in this unit. This method has proved to be the most effective in getting the students to talk about themselves.

PART II: LABORATORY EXERCISES

The laboratory part of the unit was confined to optical illusions, mazes, trial and error learning, habits and reasoning. The main idea of this division was to have the students understand the basis of learning and the factors involved in the process. Mimeographed mazes were used and the students tried to improve their time of tracing the mazes in successive attempts, thus demonstrating certain elementary processes of learning. Various questions relating to learning were asked and answers recorded. Several problems in reasoning were given and the students were timed, then they made up their own problems and tried them on their partners. A lecture on habits was given by the teacher in an attempt to show how important good habits are to effective living.

PART III: UNDERSTANDING YOURSELF

In this phase of the unit a booklet* was used with a psychiatric approach to personality. The contents deal with teen age personalities and the mental mechanisms used by students to satisfy their emotional needs. The object of using this reference was primarily for organizing, integrating, and correlating the previously learned materials so that retention and practical use of the knowledge would be assured. The immediate retention of the material was good as evidenced by the answers given on the tests. The tests were partially objective and partially subjective; there were matching questions, true false, multiple choice, completion, and essay questions of the problem type. The amount of future retention of this material will depend upon how much insight each student gained during this study and the degree with which he applies this knowledge to his own personality.

As mentioned previously, the students were given two tests: a pre-test, covering various phases of mental hygiene and an evaluation test, covering the same material but given at the end of the unit. Ten questions from the pre-test were compared to ten questions from the evaluation test. The students were asked not to

* William C. Menninger, *Understanding Yourself* (Chicago: Science Research Associates, 1948).

This ingenious and resourceful student developed a working model which responds electronically to visual and other stimuli. Any class can utilize simple mazes, optical illusions, and similar laboratory facilities to explore human psychology, sensations, and elementary concepts of learning theory. (Courtesy of Cleveland Public Schools)

A student of the Henry Grady High School explains her project on sensations to an attentive audience at the Atlanta Science Congress. (Courtesy of Atlanta Public Schools)

A COMPARISON OF TEN QUESTIONS FROM THE PRE-TEST AND TEN QUESTIONS FROM THE EVALUATION TEST

Questions	*Yes*	%	*No*	%	*Undecided*	%
1. Are you happy?	44	73.3	14	23.3	2	3.3
2. Do you like school?	48	80.0	8	13.3	4	6.6
3. Do you have any knowledge in regard to sex?	34	56.6	23	38.3	3	5.0
4. Do you like people?	45	75.0	7	11.6	8	13.3
5. Are you easily upset when people talk about you?	15	25.0	41	68.3	4	6.6
6. Would you like to improve your personality?	42	70.0	6	10.0	12	20.0
7. Do you have personal problems?	29	48.3	22	36.6	9	15.0
8. Do you know what mental hygiene is?	12	20.0	32	53.3	16	26.6
9. Do you feel like exploding sometimes?	30	50.0	25	41.6	5	8.3
10. Do you have different interests?	22	36.6	35	58.3	3	5.0

FIGURE 1. PRE-TEST

Questions	*Yes*	%	*No*	%	*Undecided*	%
1. Are you happy?	52	86.6	7	11.6	1	1.6
2. Do you like school?	57	95.0	3	5.0	0	0
3. Do you have any knowledge in regard to sex?	52	86.6	6	10.0	2	3.3
4. Do people like you?	53	88.3	5	8.3	2	3.3
5. When people mention things about you does it concern you?	6	10.0	49	81.6	5	8.3
6. Did you improve your personality?	55	91.6	2	3.3	3	5.0
7. Have you reached some understanding of your problems?	42	70.0	14	23.3	4	6.6
8. Do you have a better concept of mental hygiene?	43	71.6	10	16.6	7	11.6
9. Have you become more tolerant of others?	41	68.3	7	11.6	12	20.0
10. Has mental hygiene opened new interests for you?	39	65.0	13	21.6	8	13.3

FIGURE 2. EVALUATION TEST

sign their names to assure anonymity. The data in Figures 1 and 2 present the results of the ten questions taken from the pre-test and the evaluation test.

The significance of these two charts can be determined if one examines question number one on the pre-test and then compares it to question number one on the evaluation test. These questions represent the ten most consequential aspects of the unit. If one examines each question and compares the percentages

of the two tests, it can readily be seen that student growth was generally favorable in terms of the objectives which the author intended the students to attain. It is also significant that faulty knowledge in some cases must have been corrected in the teaching of this unit because some of the undecided students shifted their answers to more favorable answers in the evaluation test.

SUMMARY

Several generalizations and conclusions may be permitted from the teaching of this experimental unit in mental hygiene.

On the basis of the results, some of which have been presented in Figures 1 and 2, it was clear that a class in biology offered an excellent opportunity to approach this subject. Moreover, this subject could be taught by the group method.

The approach to an understanding of mental hygiene can be made through individual study and group discussion with gradually developing insight.

This report does not imply that the author has solved the problems of adolescents but rather that he has recognized some of the problems and tried to do something constructive regarding them.

14

MEETING THE NEEDS OF THE GIFTED STUDENT: TWO EXAMPLES

In 1953, the National Science Teachers Association published *Selected Science Teaching Ideas of 1952.* This was a selection of reports that were submitted by science teachers in the first annual program of Science Achievement Awards sponsored by the American Society for Metals and conducted through the Future Scientists of America Foundation of the National Science Teachers Association. The following two accounts appeared originally in this volume, of which the present author was editor, and are reprinted here with the permission of the National Science Teachers Association.[1] In each instance, the account is presented substantially as it first appeared together with an introductory statement which will help the reader interpret the account.

Earlier chapters have stressed the importance of locating and stimulating students of ability. These two accounts suggest two different procedures whereby this is being done.

> To us, one thing is clear. There are certain students who can become competent scientists. Whether they will or not depends in part on us. These students should be given an opportunity to develop their skills at the earliest opportunity. Since there is

[1] R. Will Burnett (ed.), *Selected Science Teaching Ideas of 1952* (Washington: National Science Teachers Association, 1953).

a paucity of selection techniques, it is equally clear that where wide opportunities are available, where enlightened science teaching exists, interested students whose gifts yield to the opportunities will seek to fulfill themselves in science.

NOTE: *This quotation, from the following article by Paul F. Brandwein, formerly chairman of the Department of Science, Forest Hills High School, New York, represents a growing recognition of the importance of locating, and providing sound training for, those children whose flair for science learnings make them likely prospects for science careers.*

The difficulties in both selection and training of such children under our mass-education system are quite real. That they are not insurmountable is clearly indicated in this article, which outlines a plan that has been in successful operation in one high school for a number of years.

Someone has said that the gifted child is the really "retarded" child in our public schools. There is truth in this accusation. Here is a plan for a richer and more vital science program for the science-gifted child. It should receive the most careful scrutiny of all science teachers. It will require adaptation, for circumstances differ. But the main thesis of the plan is eminently sound.—R.W.B.

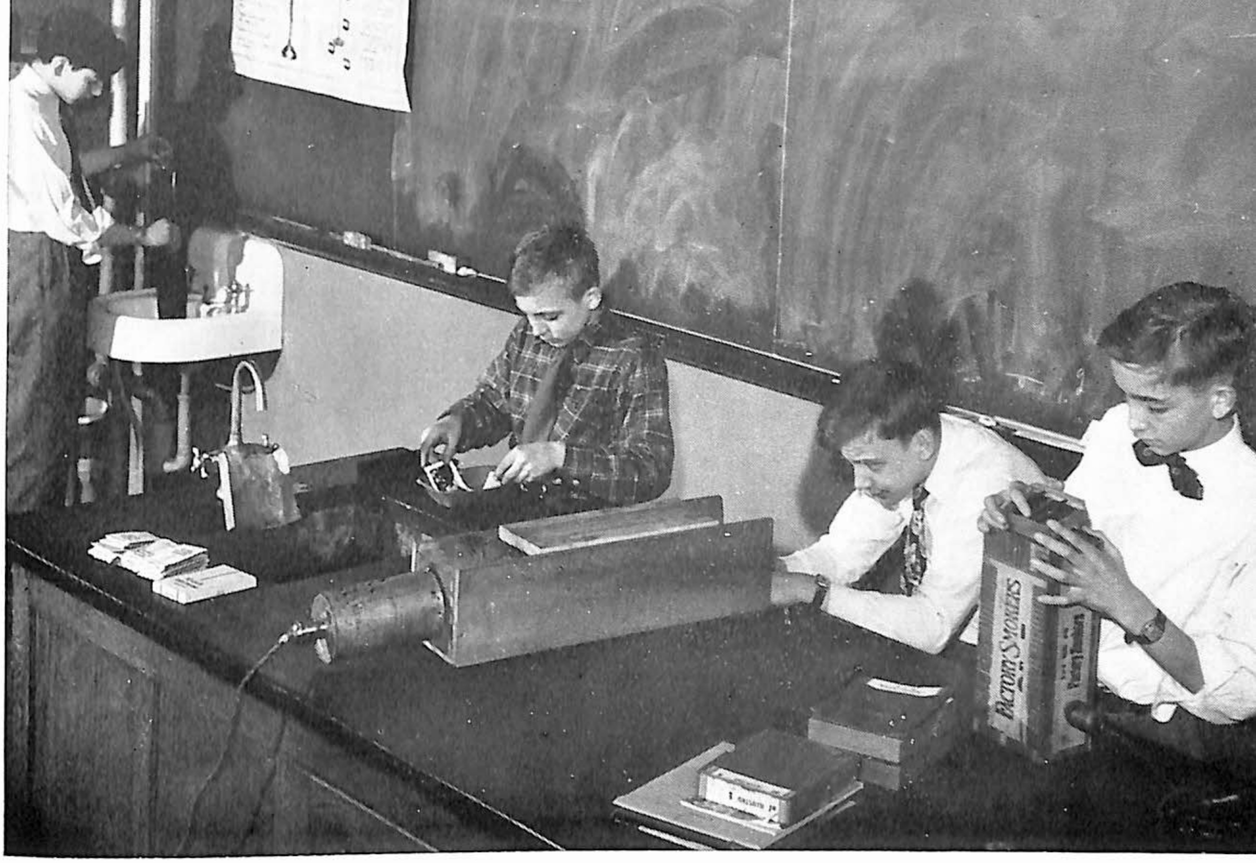
THE SELECTION AND TRAINING OF FUTURE SCIENTISTS: A PLAN FOR HIGH SCHOOLS

Paul F. Brandwein

Anyone who involves himself in even casual contemplation of present events, and projects those into the foreseeable future, is justified in concluding that there is presently a great need for scientific personnel and that this need will persist for some time to come. If this conclusion is valid, it seems obvious that these scientists must come from our school populations.

Much time would be lost in speculating whether the high school is the place for early specialization, more appropriately called concentration, in science. The facts are that such concentration can occur on the same basis that students concentrate on art, or music, or athletics, or drama, without a loss of the educational benefits of a general and exploratory nature which fall within the purview of secondary education. In short, the aims of general education are not nullified if there is added concentration in one area or another, a concentration not to be confused with the kind of specialization occurring on the college level.

It is my purpose here to describe the preliminary work done by a group of devoted teachers in the training of "future" scientists in the Forest Hills High School. The school accepts students with varied gifts, opportunities, and economic backgrounds. The fact that this article will concern itself with one high-school method which has proved useful in discovering, encouraging, and training

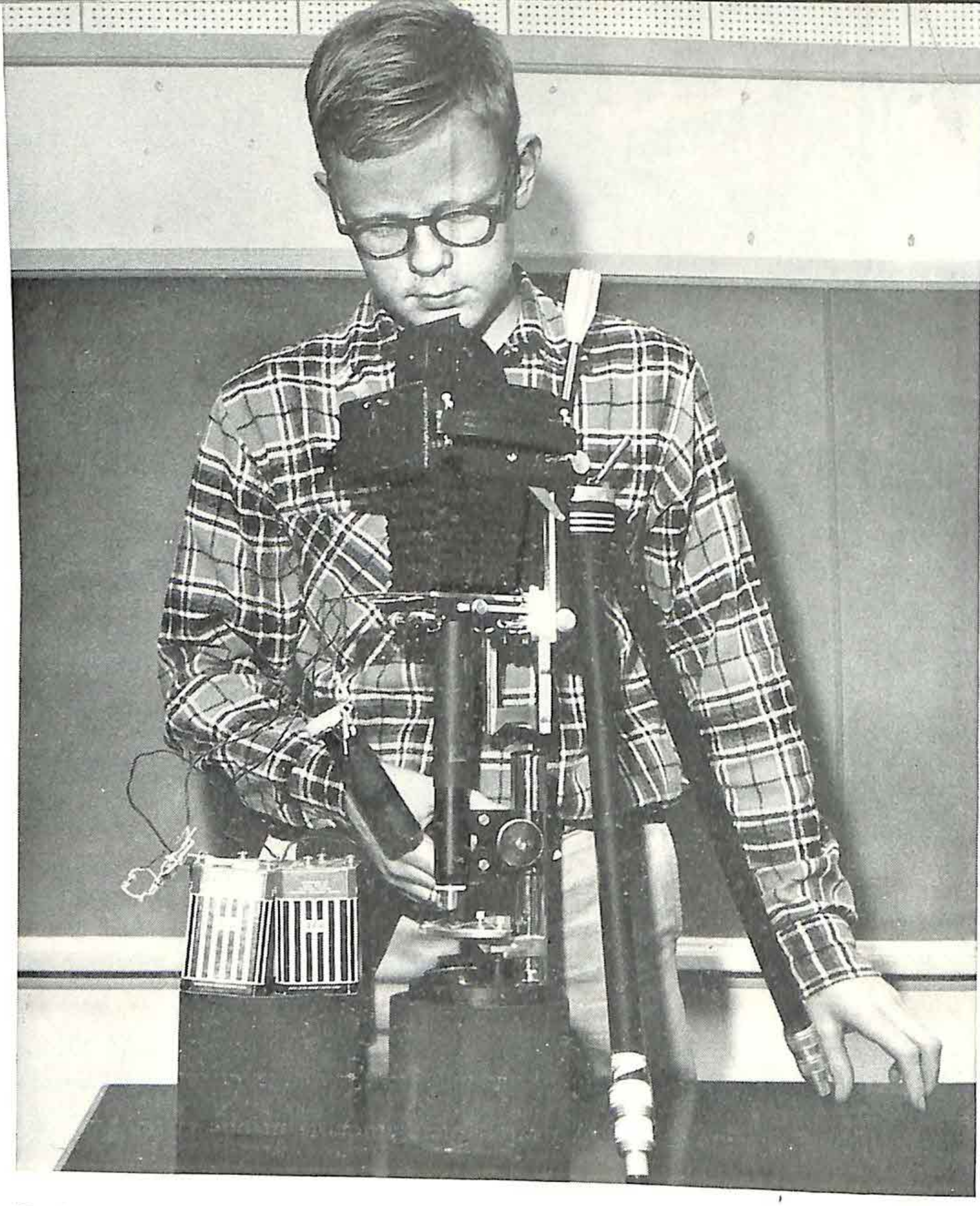


The progress of students who show any signs of distinguishing themselves in science is noted during the first few months of the freshman course. Attention is given not only to the gifted students but also to those who show an ability to work with their hands. (Courtesy of Cleveland Public Schools)

science-talented students should not lead us to think that science work begins in high school. Science programs are beginning to extend into the elementary school. Soon, we shall have a closely knit science education during the 12 years of public-school training. The effects on science and scientists of such a program are not difficult to envisage.

Let us follow an entering freshman class of approximately 400 students at the Forest Hills High School (population 3,000). All of these students take a course in general science. This is designed to further understanding of the common phenomena in their environment, the areas of life and living which science might help to solve, such as the use of natural resources, the use of energy for doing the world's work, the problem of getting along with other men, and the conquest of disease. The first step in selecting and training the prospective scientist occurs here.

The progress of students who show any signs of distinguishing themselves in science is noted during the first few months of the course. Attention is given not only to the gifted students but also to those who show an ability to work with their hands—those who may have a "hobby" interest in science as well as to those



During the second semester this program of guidance continues. The result is that many good students enter into this so-called extracurricular science work. It is our belief that this work is not extracurricular but should and must be an integral part of school work in any science training program. (Courtesy of San Diego County Schools)

whose grades are low. These first distinctions are vague, and we would have them so. For our purpose is to give each student the environment which will enable him to make the utmost use of his gifts and opportunities.

At the end of the first term, those who have shown an interest in as well as an ability to work in science are given an opportunity to work in our laboratories during their free periods before, during, and after school. Those who are interested generally ask for this opportunity. Others who have ability—as shown by

their work in class—are invited to work. Some of the activities they may choose include the following:

1. Preparing teaching materials in chemistry, physics, or biology.
2. Assisting a science teacher in his field of special interest.
3. Maintaining a large school museum of a wide variety of living and preserved specimens.
4. Maintaining a vivarium of forms particularly useful in biological work. Here students learn to maintain insects and mammals as well as cultures of the common protozoa and algae.
5. Engaging in science work in a variety of activities such as "The Science Journal" and the Chemistry, Physics, Biology, or Engineering clubs. They may help make models in the Bio-Arts Club. The Museum Curators, the Science Projects, the Cancer Committee, and the Laboratory Technicians' Club offer opportunities. This club program is broad, having been made so purposely in order to attract and hold those interested in science.

During the second semester this program of guidance continues. The result is that many good students enter into this so-called extracurricular science work. It is our belief that this work is not extracurricular but should and must be an integral part of school work in any science training program.

Our students go on to a second year of science work. There are many factors responsible for this continuing study. Two not inconsiderable ones are the sympathetic viewpoint toward the study of science of the administrative officers and the guidance department of the school and the favored economic position, in general, of the student body. But we also feel that the wide program of science activity offered is in itself a factor.

In the second year of science, selection of students for special science training begins. Toward the end of the second term in general science, students are selected (on the basis of I.Q. tests, reading scores, and grades in the first three terms of science) to enter a so-called Science-Math Honor class or classes, depending on the number available. Out of 400 entering students, some 40 to 60 find themselves in this group. Those students whose programming difficulties make it impossible for them to enter the class are nevertheless given opportunities for similar work.

These students will enter upon three years of enriched science and three years of enriched mathematics, making a total of four years of science and four of mathematics each. Generally, students of the highest caliber are found in this class. Among them are the students who are in the first quartile of their graduating class. Regularly, the first 10 in scholastic standing are to be found in this honor class.

Several purposes are served by having these students in one class. They are

These selected students will enter upon three years of enriched science and three years of enriched mathematics, making a total of four years of science and four of mathematics each. (Official photograph, Board of Education, City of New York)

given a different course of greater difficulty, of more advanced material. They are capable of attaining a high appreciation of scientific method and its social implications. They are given work which stimulates them to develop high efficiency in the laboratory and field. More important than these, perhaps, is that considerable time is spent in personal guidance, so that the opportunities and advantages of entering fields of science are opened to them.

It should not be assumed that these are the only students who enter upon further work in science. Our responsibilities in science and education are twofold:

1. We are responsible for a program of general education. This attempts to give those who will not become experts in science the basic understandings, skills, and appreciations that will enable them to cooperate closely with those who will become, or are, experts. This program must also, we feel, have special and practical application to the problems of living, so that the student sees scientific methods at work in solving his personal and community problems.

2. We are responsible for a program of special education. This attempts to select and give special training to those who may become our scientists of the future.

Thus, while practically 70 to 75 per cent of our student body of 3,000 is taking science work each term (many of the students elect four years of science) approximately 200 to 240 students are in this special science program. Are we justified in making this selection? We have permitted students with scholastic averages of 80 to 85 to enter this classification and have given them the same training. The student with a special hobby such as radio or the collection of insects is also selected, regardless of his grades. Whether we are justified depends on the data we will gather from the future achievements of these students in collegiate and postcollegiate work. Every student is given the opportunity to show his ability and avail himself of special training, but we have found that those who have an average grade of 90 or over are able to take the best advantage of the type of training to be described below.

The students selected each term are given the opportunity to—

1. Engage in some "original" research work on the high-school level. Each student is under the close guidance and observation of a teacher. (This work will be described briefly later.)
2. Learn the expert use and operation of laboratory equipment of all types (analytical balance, microscope, electric oven, autoclave, etc.).
3. Learn laboratory techniques (histological, bacteriological, techniques of analytical chemistry, work with glass, etc.).
4. Gain special skills in shopwork, including handling of common materials, wood, metal, etc.
5. Engage in library research, including college texts in biology, physics, and chemistry and other pertinent materials.
6. Take adequate training in mathematics.
7. Prepare exhibits of their work for demonstration before other students, at science fairs, or local exhibitions.
8. Prepare reports of their work (in their senior year) in writing for the school science journal or for other journals.
9. Engage in seminar activity at regular meetings of the Forest Hills High School Science and Mathematics Honor Society. Students who have shown competence in science are eligible for election to the society. Students who offer the best reports of their work will in turn be invited to submit their work at a Biology Congress sponsored by the New York Association

of Biology Teachers or to exhibit their projects at the Science Fair sponsored by the Federation of Science Teacher Associations of New York.

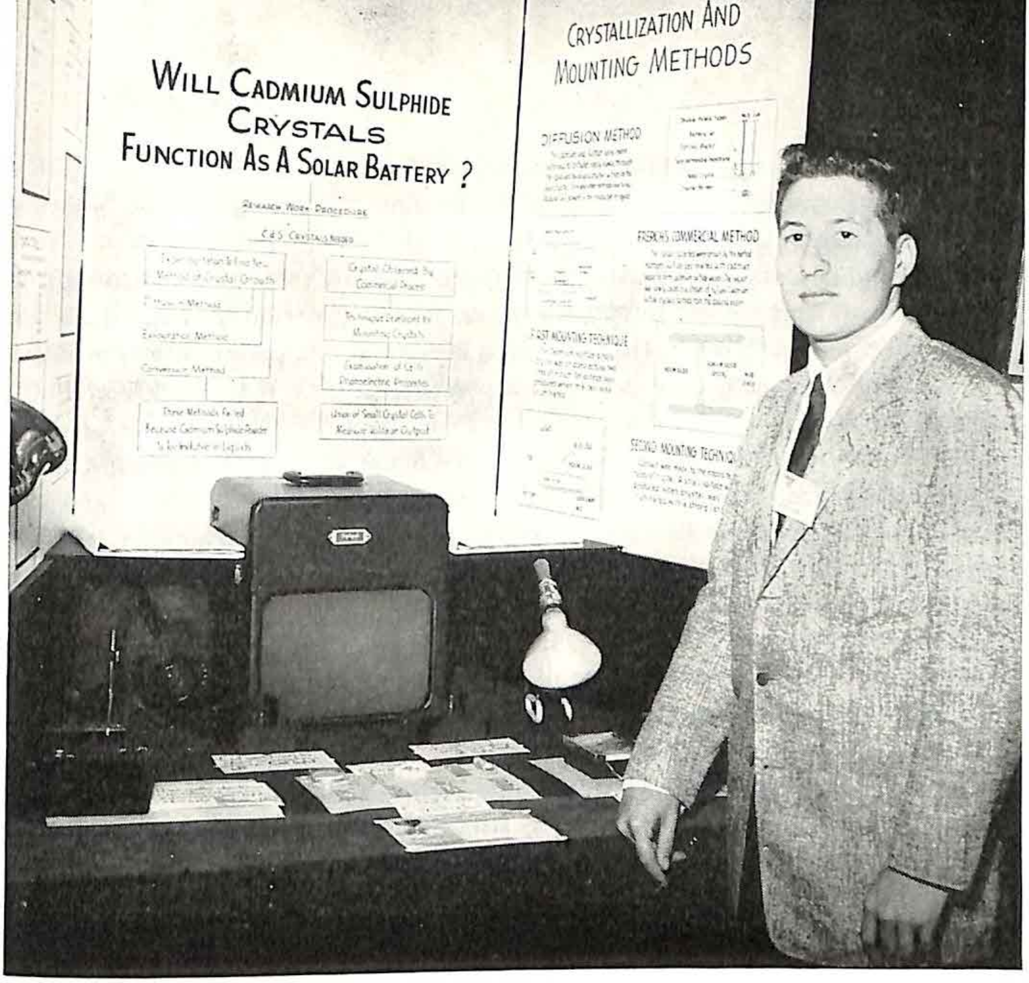
10. Engage in the Annual Science Talent Search of the Westinghouse Educational Foundation.

This is the basis for what may be called the TRAINING METHOD for selecting science-talented students as opposed to the TESTING METHOD. Reliance is placed on the observation of these students at work rather than on any given battery of tests. This method is in its preliminary stages of development, but it is described here because of its relationship to the problem of staffing our science laboratories.

After a half year in this honor Science-Math class, the students who wish it are given the opportunity to enter an Advanced Science class. This is in effect an additional period of science. However, it is not spent in classwork per se but in the laboratory; it is a period where a student may select his own project and solve it in the laboratory. Some students continue these problems at home; many work in the school laboratory before and after the regular school schedules. It is a gratifying sight to watch young people tackle a scientific problem and, using their own intelligence without any outside interference, emerge with a solution.

Where is the teacher in all this? Generally speaking, when a student asks a question we return with a question which will put him on the track if he uses his brain and his other resources including the library. If a student seems to be way off the track, the teacher's questions may bring him nearer the goal desired. The procedure is not to give the student answers which he can discover for himself by painstaking work. In addition, the teacher is constantly aware of the extent of progress by his observations in the laboratory (looking over shoulders) and by evaluating the monthly reports the students give him.

In this Advanced Science class, the mature scientist could see a picture of the scientist-in-embryo. And this is especially true of the research activity engaged in by these youngsters. In most cases, the student faces a problem he has never faced before. No solution is available in textbooks, and it may take two or more years of work to reach even a tentative conclusion. For instance, do zygospores of Rhizopus nigricans germinate? Many textbooks assume such germination. Several of our students find no such evidence on the basis of their investigation. They find their conclusions supported by authorities in the field. How long does digestion take in the food vacuoles of different protozoa? Why does Chaos chaos appear to have only a regional distribution? What factors influence sporting in species of Coleus? What effect does the gas produced by Tribolium confusum have on other insects? Other work includes a study of the embryology of Physa, diapause in Cecropia and other insects, development in vitro of certain plant embryos, studies on a modified method useful in the recovery of silver in photography, the structure of soils in the vicinity of Queens, studies on aberrant electrostatic effects, meteors, background radiation in the Forest Hills area, inversion in Volvox, sporulation in lager yeast, the influence of sun spots on



In this Advanced Science class, the mature scientist could see a picture of the scientist-in-embryo. In most cases, the student faces a problem he has never faced before. No solution is available in textbooks, and it may take two or more years of work to reach even a tentative conclusion. Picture of a Henry Grady High School student and his project at the National Science Fair. (Courtesy of Atlanta Public Schools)

agriculture, a modified circuit breaker and various other studies in biology, chemistry, physics, geology and other fields. There is little doubt in our minds, as we observe these young people at work, that they are using the methods employed by the professional scientist in his experiments.

And as they work, they grow. They make the scientist's methods of thought their own—at least in regard to the problem at hand. And it is encouraging to find that they feel that these methods hold much promise for use in investigating social as well as natural phenomena.

This early training and emphasis in the social responsibilities of scientists is of the utmost importance. These boys and girls are still plastic. Perhaps if we train our students in high school and even earlier to see themselves as citizens first and specialists later, we shall not have the situation which Dean Harry J. Carman describes in these terms: "In public life we are ruled by scientific ig-

noramuses, and in the scientific laboratory we have, for the most part, political and social illiterates." The elimination of this state of affairs is a prime objective of our program of general and special education.

At the end of the second year of high school we have, then, 40 to 60 youngsters who are ready and willing to embark on an extended period of work. Each day for two to three years, they have one period of science, one period of mathematics, and one period of laboratory work on a personal project, if they wish it. Those who do not work in school generally work at home. In doing their personal project work these students must read source material, plan experiments, order materials, construct equipment—in short, over a period of two years, carry out in a small way the methods which serve the scientist. Their teachers are ready to advise them, but advice is forthcoming only when the problem presented is worthy of consideration by the sponsor and is not indicative of laziness, poor thinking, or poor working method. In the case of the latter, the student is given whatever guidance is advisable and turned back to his work.

During the following two-year period (sophomore-senior), many students drop out of the work. Some find that athletics and social events are more important to them than science; others are not fitted—through lack of even the simplest manual skills—to carry on the work; still others lack originality. A few are lacking in honesty or a sense of responsibility and are advised by the sponsor to seek other work, but only after failure has attended many attempts to produce desirable changes in attitude by methods at our disposal. And, of course, there are those who cannot learn to work with others. Again, we have never released any of these until attempts have been made to make desirable changes, and in some instances we have retained these youngsters till the bitter end—especially when their basic qualities have warranted it.

In any event, by the beginning of the latter half of the senior year we have perhaps 10 boys and girls who have participated in most of the 10 activities previously listed. In addition, these students are most skillful in grasping scientific concepts, projecting them, and using them to solve scientific problems. We believe they have the ability to be scientists.

From these 10 senior special science students, come the 3 or 4 seniors who, we believe, may be the research scientists of the future. These 3 or 4 are given a sort of apprentice training in their senior year. They are placed in industrial, college, or research laboratories to assist scientists at work. For this we are grateful to the many individuals in college and industrial laboratories who have given generously of their time and energy. These students distinguish themselves by winning extensive honors in the various activities sponsored by different organizations.

Forest Hills High School is now ten years old. Since February 1945, when the first class which had been with us 4 years was graduated, this program has yielded 52 students whom we consider to have promise as research scientists. But approxi-

mately 400 students have been given similar training. While we feel that these 52 are of the caliber to make research scientists, we think that these 400 may also enter the scientific field and achieve a measure of success. We do not predict the same kind of success for them as for the 52 but we shall check our predictions against the actuality. For the present, it will suffice to say that these 52 have achieved distinctively high honors in high school and college as have many of the 400. The data are still incomplete for a secure evaluation of results.

Each science teacher must answer this question for himself, "What is my part in the stimulation of students with high level ability in science?" A plan which we have found useful for a high school with a population of 3,000 has been briefly sketched here. No doubt better plans are available and it would be exceedingly profitable if a description of them were available to others in the field.

To us, one thing is clear. There are certain students who can become competent scientists. Whether they will or not depends in part on us. These students should be given an opportunity to develop their skills at the earliest opportunity. Since there is a paucity of selection techniques, it is equally clear that where wide opportunities are available, where enlightened science teaching exists, interested students whose gifts yield to the opportunities will seek to fulfill themselves in science.

It is urgent that science look to its sources. These are: first, a steady flow of the highest type of young men and women; second, the facilities to train them. And, most important, we need—desperately—the teachers who have the training to develop the future scientists of the United States. Science must look to the development of those who are its mainspring and hope.

NOTE: *Most science teachers encourage individual student projects. But, over the nation, a small minority of science teachers make the individual project the chief or only teaching-learning procedure employed. Unfortunately, we have little substantial data with which to assess the soundness of this procedure in achieving the goals of science teaching. Do children learn more or less science content from this method? Does it contribute more or less to a disciplined approach to a problem and to critical thinking? Are student learnings less verbalistic and better retained when the project approach is used, as its proponents believe? Valid research is needed in which such questions as these are hypotheses to be tested.*

James H. Getty, science teacher in the Bala-Cynwyd Junior High School of the Lower Merion School District, Ardmore, Pennsylvania, has had outstanding success with the project method. His superintendent states: "I know of no other science teacher who has done such a fundamentally sound job of teaching science to children of various capacities, and at the same time brought the factors of initiative, invention, and enthusiasm to bear on his teaching situation."

Getty's article provides a good vignette of the individual-project method in action and summarizes the conditions, requirements, and

rewards of the method as he sees them from the vantage point of many years of experience. The photograph that accompanies the article, like other pictures in this chapter, are from schools providing special attention to the gifted.—R.W.B.

THE INDIVIDUAL PROJECT METHOD

James H. Getty

In my eighth grade science class this morning David Skillman is observing and making predictions from the clouds and homemade weather instruments. Dick Grasso is soldering connections on a one-tube radio. Near the windows Kathy Baffa is placing cloth wicks from a bucket of water to some house plants to provide sufficient moisture for the weekend. In the dark room Joyce Rutherford is learning to develop a roll of film and make prints, while at a table George Neil is completing his thirteenth article blown from glass. At the front of the room Rosemarie Stompo is etching glass by using a formula consisting of cockroach powder, sulfuric acid, and water; this information she found in a science magazine. Bill Robinson has made an incubator from store boxes, a light bulb, wire, and a borrowed thermostat. Through a lens he is observing the heart of a four-day-old chick embryo which he has just removed from this homemade incubator.

A relief map of Pennsylvania is being constructed from modeling clay by Norman Vander. Don Littlewood has assembled an observation beehive with a glass enclosed ramp. He is surprised to find from his study that some of the bees live only several months, that the hive is air-conditioned by the bees moving their wings, and that one colony consisting of approximately fifty thousand bees may make a surplus of fifty to one hundred pounds of honey in one season. At the back of the room Dick Winn has set up an acquarium in which a pair of Paradise fish are courting each other by spreading their highly colored fins intermittently. After this procedure the male forms a bubble around each egg to enable it to float on the surface. In case one bubble bursts the male repeats this process until the egg floats successfully on top.

These are a few of the individual projects underway in our science class. In addition a small museum, largely consisting of the best projects culled from the preceding classes and science fair entries, has been established in our room.

At the begininng of the semester I take time to explain fully the steps which were required in developing the former projects. The creative angle is especially emphasized because few pupils will attempt original, uncharted projects unless they are encouraged to do so. To form ideas and make associations and then, by practical application, to use materials from home and school in the successful completion of an interesting and educationally valuable project is my goal for these students.

To determine whether this type of participation appeals to the class, a poll is taken after I have explained other possible methods of classroom procedure to them. The result has consistently been in favor of using the individual project method.

The next step is helping students to make wise selections of problems. Some quickly arrive at well chosen topics, but others remain undecided. Since most students at their age are unfamiliar with the various categories of science, I describe the different fields of scientific study including basic and applied research. After several days of searching through supplementary material, the pupils are usually ready to select their subjects. A few sources for research which are available to my class are supplementary science textbooks, science fair catalogs garnered from different areas, various other catalogs on fish, electrical equipment, etc., the pamphlet *One Thousand Topics* (Science Clubs of America), and a selection of science magazines. The students are required to list five subjects which appeal to them. From these lists I make the individual assignments, keeping in mind the pupils' preferences. Each student has a different problem to work out on his own.

All scientists keep notes. Among the notes of the children I expect to discover the steps in their thinking, or as it is sometimes called—problem solving. (One categorization of the steps in problem solving can be found on page 29 of the Forty-sixth Yearbook, Part I, of the National Society for the Study of Education.) Reference to these steps is made frequently. Since the solution of our problems in daily living is based on these logical points, it is my contention that students should learn them at an early age. This results in improvement in critical thinking, and can help the students acquire the ability to apply their knowledge to new situations. I emphasize that doctors, teachers, chemists, detectives, industrial workers or home-makers all face problems, and the solutions ought to be reached through the application of sound steps of logical reasoning. To show how these steps are carried out, I often cite a hypothetical detective story and explain each step as the problem is solved. This, I find, gives the students a concrete picture.

On other pages in the students' notebooks there will be shown how the problem solving procedure has been carried out and a summary of principles, skills, and references used.

Very often I am approached with a simple question which hasn't been analyzed and is well within the realm of the student's comprehension. In such a situation I remind him of the steps in critical thinking. Usually in return I get a smile and a nod as he goes back to his work. Now he is ready to take up his assignment independently, and to do his own thinking.

In order to do individual research of this nature and to get sufficient facts there should be a library of books, charts, models, and magazines built up in the classroom. Of course the more ambitious students will supplement these sources with additional material found in the school and public libraries.

Some suggestions for this schoolroom collection include books and scientific

magazines which deal with a wide variety of fields in general science, biology, physics, chemistry, and health. It would be helpful to add books about hobbies and applied science such as photography, meteorology, house plants, glass blowing, astronomy, bees, conservation, and any others along similar lines that might be obtainable. Excellent sources of materials are the national and state governments, the Science Clubs of America, such magazines as *Popular Science* and *Popular Mechanics,* and such industrial firms as Westinghouse, General Electric, and Eastman Kodak.

From books and other sources of information the facts and principles are collected and noted by the students. To make sure the facts are understood I require a diagram or a series of diagrams to be drawn. The correct interpretation of words is vital because an original diagram, well labeled and explained, can't be made unless each word is understood. The lack of interest in science can often be traced to poor comprehension. With understanding there is interest and, usually, success follows.

Naturally, many subsidiary problems arise and these must be handled by the same general procedure used in solving the major ones until a satisfactory conclusion is complete. All the facts, principles, theories, and answers to these minor problems are used in forming conclusions which should be directed toward the major question. An overall picture of this summation should be made.

Using this picture, students may sometimes construct models from wood, cardboard, plaster of paris, modeling clay, paper, Erector sets, old clocks, and other mechanical or electrical gadgets brought from home or bought at a junk yard. Perhaps from some of these materials a student can make an automatic fish feeder—a device he has never seen and, possibly, which has never existed. Such a project is a thrilling experience for the pupil. Some future scientist may be laying the foundation for a successful career through his careful attention to some such exciting project.

Of course it is often unnecessary or even impossible to make a model. Sometimes a series of smaller construction projects is created as each minor problem is solved, or fact, principle, or theory is established. A good example in the study of electricity is the construction of a compass from a cork, a needle, water, a saucer, and a magnet; an electro-magnet from a nail and some wire; a telegraph from tin, nails, and wire; telephones with carbons from dry cells, a tin can, a cigar box, and wire; an induction coil from glass jars, soft iron core, and insulated wire, a crystal set; and a one-tube radio set.

Certain tools for this type of work are a necessity. Among these should be included claw hammers, wood, hack, and coping saws, soldering iron, squares, screw drivers, compasses, cork-borers, tongs, forceps, a blowtorch or burners, planes, tin snips, assorted nails and screws, and several work-shop tables with vises attached. My students have brought some tools from home to add to those we had previously accumulated. The more interest the child shows the more eager he is to bring in equipment.

A student in the Henry Grady High School, working on an independent research project in hematology. (Courtesy of Atlanta Public Schools)

Many parents and fellow teachers have been astonished at the achievement of these junior high school boys and girls. And, I confess, I tend to feel the same way as I direct them every day of the school term. I have a feeling of personal growth and accomplishment as I see the projects materialize and go on to successful completion. In this kind of teaching-learning situation there is little chance of one's teaching becoming stagnant. The individual project method is challenging and stimulating to students and teacher alike.

STATUS OF THE PROFESSION

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SCIENCE TEACHING AS A PROFESSION

A profession is characterized by at least four features which distinguish it from vocations in general.

1. Any fully developed profession has produced a considerable body of theory and practice in which its practitioners require advanced training. This higher training is at least that sufficient for the baccalaureate.
2. The standards of success and accomplishment are professional rather than financial; that is, a professional man is judged primarily by his professional skill as evaluated by qualified colleagues rather than by the amount of money he makes.
3. The profession disciplines its members under certain clear standards of competence and ethical practice and limits the right to practice in the profession to those who are judged competent by these standards.
4. Practitioners of the profession set standards, maintain and advance them, and see to it that standards are enforced through professional associations.

The profession of teaching has not achieved full development by these criteria. There is a large and still-growing body of theory and practice, but training in it varies considerably. For every teacher of science who is competent in his discipline and in teaching, there are others who are woefully inadequate. The financial rewards of teaching are far below what they should be, and teaching as a profession in this country is not accorded the respect that is accorded other pro-

fessions. It is a hardy soul that can develop self-respect when respect is not accorded him by others. But it is clear that whatever standards of success do exist are of a professional rather than a financial nature. Standards of competence, however, are almost nonexistent in any objective and definable sense. This being true, the professional associations can do little or nothing, formally, about disciplining practitioners.

SOME STUDIES ON THE TRAINING OF SCIENCE TEACHERS

Let us examine certain data which will aid us in assessing the status of the profession of science teaching.

In 1953, Theodore Nelson completed a doctoral research which presented comprehensive data concerning the training, work, and responsibilities of science teachers in the state of Illinois. The data which follow are from this study[1] and disclose the inadequacies in training for the work these teachers were required to perform.

The group studied was composed of 119 beginning teachers. Of this group, 66 had been trained in teachers colleges, 29 in universities, and 24 in liberal-arts colleges. Only 13 of the group had earned master's degrees.

Seventy-eight per cent taught in small schools, enrolling fewer than 250 students. Typically, they were responsible for teaching all or most of the science offered. Only 3 of the 119 taught only one science, and 92 taught nonscience courses as well. Such teaching must involve a broad and reasonably thorough preparation in the sciences, if the courses are to be well taught; but of the 119, 7 had no background in biology; 22, none in chemistry; 29, none in physics; 33, none in mathematics; 91, none in geology; 102, none in meteorology; and 104, none in astronomy. As to their training in education, 4 had had no work in educational psychology; 5 had not done practice teaching; 63 had no training in evaluation; and 89 had taken no work in curriculum development.

The median semester hours of study reported in the natural sciences were as follows: physics, 8; chemistry, 12; biological sciences, 15; and all sciences combined, 41. The median hours of course work reported in education were as follows: practice teaching, 5.3; evaluation, 0; educational psychology, 3; curriculum development, 0; and all other courses in education combined, 5.3.

Of the 81 who taught general science, 22 had not majored in any field of science. The range of work in biology was from 0 to 77 hours, with a median of 15 semester hours; in chemistry, from 0 to 45.3 hours, with a median of 15; in physics from 0 to 55 semester hours, with a median of 10; and, in all other science fields combined, the range was from 0 to 37 semester hours, with the

[1] "Competencies Desirable for Beginning Science Teachers as Viewed by Administrators and Science Teachers in the State of Illinois" (Doctoral dissertation, University of Illinois, 1950).

median at 0. Of these 81 teachers of general science, 4 had had no work in biology; 10, none in chemistry; and 14, none in physics. Of the 81, 47 had had no work in *any* of the following fields of importance for teaching general science: geology, astronomy, and meteorology.

Thus, using the median or below as examples of the science teachers in Illinois, we find that students of at least 50 per cent of the beginning science teachers in that state probably suffer a substandard course taught by a teacher incapable, through lack of knowledge, of bringing vitality to his course, of moving away from rote teaching from a textbook, or of encouraging and stimulating critical analysis.

Many teachers and administrators recognize this weakness. They asked for "training spread over several science fields, and, in addition, with intensive training in one field of science," in response to questions in the Nelson study. The fault of inadequate preparation does not lie solely with the individual teacher or with the high school principal; institutions which prepare teachers must assume part of the responsibility.

In 1952, Deloach and Hall studied the undergraduate training of chemistry teachers in the state of Alabama. Out of 167 teachers, almost 23 per cent had taken general chemistry only; 3 per cent had a background of general chemistry and qualitative analysis only; about 11 per cent had only general chemistry and organic; 7 per cent had taken general chemistry, qualitative and quantitative analysis, and organic chemistry; and only 2 per cent had taken these subjects plus physical chemistry.[2]

Magnuson studied the preparation of elementary and secondary teachers of science in the state of California. Out of the total of 1,552 teachers who reported, 277 teachers had neither a major nor a minor in science fields, 364 had a minor but no major in science fields, and 891 had majors in science. Eight per cent of the high school full-time science teachers in the state had not completed a college education (bachelor's degree)![3]

Fletcher Watson reported the preparation in science of high school teachers in the state of Massachusetts in the summer, 1949, issue of the *Harvard Education Review*. The average semester hours of credit in chemistry of the high school chemistry teachers studied was 23.8. The average semester hours of physics taken by the physics teachers was 16.4, and the average semester hours of biology taken by the biology teachers was 17.1. These averages are shamefully low. Although 29 of the 95 chemistry teachers in his sample had taken more than 30 hours of chemistry, another 24 teachers had taken less than 10 semester hours. Although 14 of the 109 physics teachers had taken more than 30 hours in their major subject, another 35 had taken less than 10 hours. Only 17 of the 96 biology teachers had

[2] W. S. Deloach and A. R. Hall, "The Undergraduate Preparation of High School Chemistry Teachers in Alabama, 1948–49," *Science Education*, Vol. 36:27–28 (February), 1952.

[3] H. W. Magnuson, The Preparation of California Public School Teachers (Doctoral dissertation, Stanford University, 1949).

taken more than 30 semester hours in their discipline, and 38 had less than 10 hours in biology to their credit.

In 1945, two reports were published that disclosed the patterns of courses taught by science teachers in Colorado and Pennsylvania. The data for the teachers in Colorado may be summarized as follows:[4] only 11 per cent of the biology teachers taught biology alone; only 7 per cent of the physics teachers taught physics alone; only 7 per cent of the chemistry teachers taught chemistry alone; 31 per cent of the science teachers in Colorado taught two sciences; 24 per cent of the science teachers taught three or more sciences.

The data for the schools of Pennsylvania may be summarized as follows:[5] Of the physics teachers, 10 per cent taught physics only; 42 per cent taught two subjects; 34 per cent taught three subjects; 11 per cent taught four subjects. Of the chemistry teachers, 13 per cent taught chemistry only; 48 per cent taught two subjects; 28 per cent taught three subjects; 8 per cent taught four subjects. Of the general-science teachers, 25 per cent taught general science only; 56 per cent taught two subjects; 17 per cent taught three subjects. Of the biology teachers, 30 per cent taught biology only; 53 per cent taught two subjects; 14 per cent taught three subjects; the 3 per cent remaining taught four and five subjects.

In 1941, the author conducted a comprehensive questionnaire study regarding certain aspects of science teaching in the nation. A part of this study was concerned with the training of the science teachers and their judgments concerning the adequacy of that training. The following data are from this study. They refer to responses of a representative sample of all science teachers in the United States in 1941. The reader can secure more information about the study by referring to the published report of the committee.[6]

> Ninety per cent of the respondents stated their belief that the science courses they took in college should have given more attention to the effects of scientific achievement on society. Only 3 per cent stated a position in opposition to this majority viewpoint.
>
> To the question, "In general would it increase the value of the educational program if distinct fields of specialization were set up in such functional areas as the cause and control of disease, nutrition, economic entomology, human physiology, and material resources of the earth, rather than in the areas of zoology,

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[4] A. E. Winans and F. C. Jean, "Educational and Professional Status in the Public Schools of Colorado," *Science Education*, 29:133–136 (April–May), 1945.

[5] W. A. E. Wright, "Subjects Taught by Science Teachers in Third Class School Districts of Pennsylvania," *School Science and Mathematics*, 45:45–53 (January), 1945.

[6] National Committee on Science Teaching, *The Education of the Science Teacher* (Washington: American Council of Science Teachers, 1942), p. 44.

botany, chemistry, and physics?" 62 per cent answered yes, 21 per cent were uncertain, 17 per cent answered no.

Fifty-four per cent of the teachers believed that science teachers in general were too highly specialized in one field for adequacy on the job. Seventy-four per cent believed that teachers of science should specialize in the broad area of "natural sciences" rather than in one of its divisions.

Of the fields which teachers stated should have received more attention in *their own* training, the following secured more than 50 per cent "votes": astronomy, 74 per cent; bacteriology, 53 per cent; meteorology, 67 per cent; geology, 59 per cent.

These reports on the training of science teachers lend considerable support to the judgments of the Cooperative Committee on Science Teaching.[7]

Science teachers are not properly trained for the actual teaching assignments they must accept as beginning teachers working for the most part in small high schools. . . .

Most new teachers commence their work in small high schools because the large schools require teaching experience of candidates for positions. The beginning teacher in a small school nearly always must teach at least three different subjects, and often four or five. . . .

The majority of students in high school need a kind of science course which fits their present interests and their future needs as citizens. Such courses must be well taught to be successful, with thorough treatment of topics taken up and with application to consumer problems, personal and public health, the use of conservation of natural resources, international relations, and so on. . . .

In the small high school the need is for a science teacher who is trained broadly enough to teach the varied science aspects of general education, and who is also well enough trained in one or more specific sciences to teach the prospective scientist the things that will enable him to get started on the path of specialization. . . .

Many colleges have adopted standards of concentration in a major department which make it difficult and often impossible for an undergraduate to secure a good preparation for teaching in as many as three science fields. While this may be good for the future research scientist, it is not good for the future high school teacher. The colleges should provide opportunity for a "concentration" which shall lie not in one department but shall

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[7] American Association for the Advancement of Science, Cooperative Committee on Science Teaching, "The Preparation of High School Science and Mathematics Teachers," *School Science and Mathematics*, 46:108–112 (February), 1946.

> spread (not too thinly) over at least three subjects among the sciences and mathematics. . . .
>
> The prospective science teacher should make a study of the social consequences and historical backgrounds of science.

In general, the data and conclusions from the various studies and reports which have been presented so far in this chapter show that the science teachers of the nation, as a group, are poorly trained for the responsibilities they assume; that they recognize inadequacies in their training; and that they are forced to assume teaching responsibilities that are well beyond their capacities in terms of their training. They are often overworked; they teach with inadequate equipment and materials; and the well-trained teachers suffer from a lack of the respect which is accorded individuals with comparable training who work at industrial-research jobs for far greater financial returns.

The kind of dynamic science teaching which has been proposed in this book requires science teachers who are well trained and capable of giving devoted service to young people and the causes of science and democracy.

Let us be frank. The great reason why dynamic science teaching has been limited is simply that there are relatively few teachers whose ability and training have made them capable of other than rote teaching *by* the text-dominated field-covering approach.

This is not a denunciation of science teachers. It is a simple statement of fact. But, if the reader is to improve his own teaching and to assist in the necessary process of advancing the profession of science teaching, he must understand the status of the profession today. The science teachers of the nation are not to be criticized. As a group they are providing selfless and valiant service under great handicaps. It is the handicaps that must be understood and removed as swiftly as possible, for the status of science teaching today is dangerously low.

THE STEELMAN REPORT ON THE STATUS OF HIGH SCHOOL SCIENCE TEACHING

The Steelman report, *Manpower for Research,* presents a searching and revealing picture of the status of high school science teaching in 1947. It is reported at length below, for it is as valid today as it was in 1947. The financial data are changed, of course, but the relative position of the teacher compared to workers in other professions has considerably worsened, not bettered. The present author concurs fully in the views expressed.

The portion of the Steelman report which we quote was prepared by the Cooperative Committee on Science and Mathematics Teaching of the American Association for the Advancement of Science by request of the President's Scientific Research Board in 1947. The statement would stand on its own merits, but the reader will be interested in knowing the composition of the committee who pre-

pared the report and the societies they represent. The committee consisted of the following.

American Association of Physics Teachers: K. Lark-Horovitz, Purdue University, and Glen W. Warner, Chicago City College
American Astronomical Society: Oliver J. Lee, Northwestern University
American Institute of Physics: Lloyd W. Taylor, Oberlin College
American Society of Zoologists: L. V. Domm, University of Chicago
Botanical Society of America: Glenn W. Blaydes, Ohio State University
Central Association of Science and Mathematics Teachers: Arthur O. Baker, Cleveland Board of Education
Division of Chemistry Education of the American Chemist Society: Laurence L. Quill, Michigan State College
Executive Committee of the A.A.A.S.: E. C. Stakman, University of Minnesota
Geological Society of America: George A. Thiel, University of Minnesota
Mathematical Association of America: Raleigh W. Schorling, University of Michigan
National Association of Biology Teachers: Prevo L. Whitaker, Indiana University
National Council of Teachers of Mathematics: E. H. C. Hildebrandt, Northwestern University
National Science Teachers Association: Morris Meister, Bronx High School of Science
Chairman: K. Lark-Horovitz, Physics Department, Purdue University
Secretary: R. W. Lefler, Physics Department, Purdue University

The Cooperative Committee on Science and Mathematics Teaching has been in existence for several years. It has issued a number of reports on the teaching of science and has undertaken its investigations on a continuing basis. Its report, which follows, merits careful scrutiny and reflection.[8]

> There is at present a serious shortage of teachers of science and mathematics.
>
> Young persons are rejecting teaching in the lower schools as a career, especially the teaching of science. The State of Michigan has 18 institutions that train teachers, with a present enrollment of over 72,000 students. Of this vast student body, only about 1,800 students will this year qualify for teaching certificates in the

[8] John R. Steelman, *Manpower for Research* (President's Scientific Research Board, *Science and Public Policy*, Vol. 4; Washington: Government Printing Office, 1947), pp. 95–99, 101–107.

elementary or secondary schools. Among these 72,000 students there are only 164 majors and 172 minors who will this year qualify as science or mathematics teachers.

The situation at the University of Michigan, with more than 19,000 students, of which a very large number are studying science and mathematics, is perhaps typical of State universities. This institution has only 35 students—some not too capable—who will this year do student teaching in physics, chemistry, biology, general science, or mathematics. Some of these have only a minor in a science. There were this year only four student teachers in chemistry and not a single student teacher in physics. Michigan needs at least twice as many teachers of science as it now has in training, and many, many more if the incompetent and the teachers with emergency certificates are to be replaced.

A similar situation is reported from the Ohio State University. For the year 1945–46, there were 25 prospective teachers majoring in 1 or more sciences and 10 in mathematics—a total of 35 majors in science or mathematics. There were no majors in physics in this group. In 1946–47 at this same institution there were 61 majors in science and 17 in mathematics—a total of 78. The total enrollment at the Ohio State University during these 2 years was approximately 24,000 each year. Since in a number of instances a senior would have two majors in the science and mathematics area, the actual number of prospective teachers available in this area during these 2 years from this institution would be respectively approximately 28 and 65. In Ohio, as in Michigan, there were a number of schools in which each of these teachers could be placed.

This is the picture in two States; the question arises, "Is it true for the country generally?" Last semester there were about 200,000 students enrolled in 24 prominent colleges and universities that educate teachers. This list includes State universities like the University of Minnesota and large teacher colleges as, for example, Colorado State College of Education and Peabody College. Note that these schools enrolled about one-tenth of the over 2 million students in our 1,749 higher educational institutions. Of these students there are only 600 who will this year [1947] qualify for the teaching certificate in science and mathematics. At the rate that industry, business and government are now picking up young scientists, we have no assurance that a high fraction of these 600 seniors will be teaching science or mathematics in high school next fall. If the approximately 200,000 students is a random sample of the 2 million or more students in higher education, then we can expect for the Nation's schools 6,000 persons qualifying for science and mathematics in high schools, and that figure obviously is wholly inadequate to

insure a good quality of teaching in the years immediately ahead.

The number of undergraduates and graduate students majoring in science or mathematics is probably a higher percentage of the total enrollment than it was 10 years ago. In 22 of these institutions, with a total enrollment of about 190,000, there are 5,700 undergraduates majoring in science and mathematics. In 22 of these schools, there are at least 3,800 graduate students specializing in science or mathematics. For example, Purdue University reports that it has 288 graduate students in the sciences. However, the young men in science are attracted so early by industry, Government, business and college teaching that they do not even bother to qualify for the teacher's certificate.

A questionnaire regarding future plans of students with reference to intent to enter college was sent to 440 high schools distributed throughout the entire state of Indiana. This questionnaire was submitted to the upper 10 per cent, by scholarship, of the graduating classes and was returned by about 2,100 pupils from 285 schools. Of this total group about 1,600 have indicated their intent to enter college, and 518 expect to make a career of science or mathematics. It should be pointed out that of this latter group 109 have specified further their intent to make high school teaching (of science and mathematics) their career. Recapitulating, 75 per cent of this select group intend to go to college, 25 per cent of the group who expect to go to college intend to make science or mathematics a career, and 21 per cent of all those interested in making a career of science or mathematics, or 7 per cent of those going to college, are at present interested in teaching in our high schools.

Early returns from a similar study carried out in the spring of 1947 in Ohio showed that out of about 2,300 seniors in the upper 10 per cent of their classes in 287 large and small schools, 1,650, or 62.5 per cent, indicated that they planned to go on to college. Of these, nearly 800, or 48 per cent, said that they planned to follow some pursuit related to science and mathematics in college. Only 89, or about 11 per cent, of this latter group indicated their intention to go into teaching. This group of 89 planning to go into science teaching is about 5 per cent of the total 1,650 from the upper tenth of graduating seniors who plan to go to college.

Reasons for the Shortage

There are several reasons to explain the present shortage of science and mathematics teachers and the lack of interest of potential teachers.

The Research Division of the National Education Association

has gathered significant statistics on this question from State educational authorities. For the year 1945–46 there were 860,000 teaching positions, of which 846,743 were filled and 13,257 were vacant. These vacancies have resulted in overcrowded classes and the employment of inadequately trained teachers on emergency certificates, with a resultant lowering of the effectiveness of instruction. A survey reported in the New York *Times* indicates that there are 123,492 substandard teachers employed during the present school year (1946–47).

The teacher shortage is most acute in States affected by shifting populations or in States which pay low salaries. In the States with most acute shortages the salaries of at least 40 per cent of the teachers were under $1,200 per year.

Between the years 1939 and 1941–42 the average annual earnings of factory workers went up 56 per cent, while the earnings of lawyers and physicians, basically more than three times the teachers' salaries, each increased about 13 per cent. The earnings of teachers increased 7 per cent. In the period from 1939 to 1944 the annual income of teachers rose from about $1,420 to $1,750, while the annual income of factory workers went from $1,320 to a little more than $2,200. Our shortage of teachers today is in a large part due to the discouraging influence of low salaries.

Over the period from 1920 to 1942 the national income has tripled, whereas expenditures for public education have remained nearly the same. The teacher shortage is largely an economic problem. In order to secure competent teachers there must be a substantial increase in the amount of money spent on education. There is adequate evidence that, as a Nation, we have the financial resources to provide the necessary amount.

Numerous studies indicate, however, that there are sections of this country without sufficient local or state resources to maintain an adequate system of education. This indicates the need to make Federal funds available for equalizing educational opportunity.

Low salaries are by no means the sole reason why qualified individuals are not attracted to the teaching profession and in particular to the teaching of science. The inherent nature of the tasks which fall to the lot of the science teacher makes special drains on his time and energy. The effective teacher of science must make use of a vast array of teaching materials. He must spend time in devising, assembling, and using demonstrations and laboratory experiments. He must know where such materials are obtainable; he must order them and keep an inventory and filing system. After use, this equipment must be cleaned and properly stored. Frequently it must be repaired. After-school clubs require additional time and effort. Nevertheless, adminis-

trators expect of science teachers the same teaching load as is expected of all other teachers. All too frequently, these teaching assignments demand a preparation beyond that which can be reasonably expected of even the well-trained teacher.

H. B. Glass reports one-third of all biology teachers as feeling that extracurricular assignment and supervisory duties reduce their efficiency in teaching biology.

In order to determine the opinion of teachers of science and mathematics regarding factors now operating to reduce their teaching efficiency, a questionnaire was printed in an issue of *School Science and Mathematics.* While a relatively small number of replies were received, the answers are indicative of a situation which makes science teaching for many an unusually difficult task.

Replies from 326 teachers, working grades 7–12, indicate that—

57 teachers lack laboratories,
100 teachers lack equipment and supplies,
91 teachers lack classrooms especially adapted for science teachers,
69 teachers lack classrooms that the science teacher could call his own,
160 teachers lack time for preparing materials for laboratory and classroom demonstrations,
61 teachers lack reference materials, books, and periodicals,
119 teachers have classes ranging from above 30 students to more than 40 in a few instances,
66 teachers have to teach too many classes per week (25 to 40 and more periods per week)
59 teachers consider turn-over in science and mathematics teachers too rapid,
125 teachers have too many unrelated extracurricular duties,
101 teachers must do extra jobs to supplement income, and
47 teachers have too many preparations per day.

One is actually appalled by the conditions, both administrative and physical, under which our teachers of mathematics and science are required to work. Nevertheless, one who visits the schools actually finds much resourcefulness and enthusiasm. If it were not for the evangelistic fervor of some of our teachers, the situation would truly be dark. This attitude is commendable, but steps must be taken immediately to prevent recruitment from being largely on such a basis.

Secondary Teachers

The limitations in the amount of training of science teachers are revealed by many studies. While exact data are not available,

there are without question many teachers of science today teaching on emergency permits. It is a reasonable assumption that in general these people are not adequately trained. Even assuming that this is a temporary condition and granting that there are many teachers trained adequately for the broad fields of science and many others adequately prepared to teach well in their fields of specialization, there is much evidence that many regular teachers are inadequately prepared or are required to teach subjects outside their areas of preparation. A committee appointed by Commissioner of Education J. W. Studebaker has reviewed the results of recent studies and in summarizing the facts one finds:

1. A conspicuous lack of training in the physical sciences in the secondary schools, so that at any one time only about 7 per cent of the total high school population is enrolled in physics or chemistry, whereas a large number is enrolled in the biological sciences (biology, zoology, botany, hygiene, and so forth.)

2. This is owing to the fact that more than half of our schools have six or less teachers and, under the present licensing and certification system, most of these schools cannot afford to hire a teacher for the physical sciences.

3. Some of the best science teaching in smaller high schools is carried on by the teachers of agriculture in States in which the time of such teachers is prorated and they do not spend all their time in vocational agriculture. In the teacher training programs set up to prepare these vocational teachers, a considerable amount of science is required.

4. The teachers now teaching science in the high schools are, in many States, poorly prepared in their respective subjects, being on the whole measurably less well prepared than trainees in the same field for industry.

5. Because only a small proportion of high school students take science at the present time, those who teach these sciences must combine science with some other subjects. Many of the teachers have to teach three, four or even more subjects which may be almost entirely unrelated. The result is that such science teaching has to be assigned to individuals whose main interest is in some other subject, for whom science was only a minor subject in college.

6. This situation could be remedied by certification of science teachers in comprehensive areas, such as a combination of the physical sciences with the biological sciences or of the physical sciences with mathematics and geography.

7. It is necessary to realize that teachers trained in such comprehensive science areas are also potential candidates for

industrial positions. Since the starting salary and the life expectancy of earnings are far higher in industry than in the schools, we must be able to compete with industry in order to attract teachers who are well trained and have aptitude in the physical sciences and mathematics. This is all the more true because men are more likely than women to specialize in science and mathematics, and men—with their family responsibilities—can less afford to continue teaching at low salaries.

Undergraduate science and mathematics courses are more often than not preparatory courses planned for people who intend to become specialists in some definite field of science or mathematics. While such courses may serve this purpose satisfactorily, they fail to give breadth of understanding or comprehension of the interrelationships existing between the many specialized fields of science and mathematics. These understandings and relationships are essential for teachers in the secondary school, where they must, at best, teach in broad areas.

The undergraduate training program for teachers of science and mathematics, to be most effective, must be a specifically planned professionalized program.

In small high schools, which are the predominant class, it is an especially prevalent practice to require such teaching combinations as, for example, mathematics, social studies, Latin, and biology. This is due to the large number of school units, which result in small enrollments, thus limiting the size of the faculty. Obviously a single individual's interests do not extend with equal depth into so many unrelated fields. Even if this is possible, the teacher load due to so many varied preparations would decrease the effectiveness of preparations.

Data assembled by K. Lark-Horovitz in 1937–1938 indicate that for a sample of 205 out of a total of 839 high schools the physics teachers were devoting 28.6 per cent of their time to physics. Only 8 teachers were reported as teaching physics only. These teachers of physics had taken an average of 4.4 undergraduate courses in physics, 4.8 in mathematics, 2.5 in chemistry, and 5.3 in education. The average number of graduate courses in physics taken per teacher was 0.65. The schools participating in this study enrolled 37 per cent of the high school students in the State.

Bulletins of the 48 State certifying agencies indicate that at present nearly all require a minimum of graduation from a 4-year college for certification in secondary school subjects. Two States still offer blanket certificates, but 1 of these requires a minimum of 5 semester hours in each unit course taught. The most usual requirement is for 15 to 18 semester hours minimum college

course work in each subject taught, but it is not uncommon to find a minimum requirement of only 5 or 8 or 12 hours in each science.

Certain findings of the committee on High School Teaching of Chemistry of the American Chemical Society seem pertinent here. They find that—

1. Many science teachers in the high schools are teaching subjects in which they have had no college preparation and many others are teaching subjects in which they have had only 1 year of college work.

2. The study involving 5,481 teachers from North Central Association schools shows that 50 per cent of the men and 61 per cent of the women physics teachers had had less than 11 semester hours work in physics, while 12 per cent of the men and 19 per cent of the women chemistry teachers had had less than 11 semester hours of chemistry.

In a study conducted by Edward F. Potthoff the teaching combinations of 3,490 teachers in 525 public 4-year accredited secondary schools of Illinois, having less than 20 teachers on the faculty, have been determined.

Certain significant facts are summarized by the author:

1. These 3,490 teachers were assigned to teach a total of 716 different subject combinations: (a) more than 75 per cent of these subject combinations were of three or more subjects; (b) nearly 30 per cent were teaching classes in three or more departments.

2. (a) Of 293 teachers of biology, only 3.4 per cent were teaching biology and one other subject, 38 per cent were teaching biology and two other subjects, and 19 per cent were teaching biology and three other subjects. These teachers were assigned to a total of 124 different combinations and were teaching 25 subjects in addition to biology; (b) of 155 teachers of chemistry only 2 per cent taught the one subject, 37 per cent taught one other subject, 44 per cent taught two other subjects, and 14 per cent taught three other subjects. These teachers taught 62 different combinations including 20 different subjects; (c) of 325 teachers of physics none were teaching physics only, 34 per cent taught physics and one other subject, 45 per cent taught two other subjects, and 17 per cent three other subjects. These teachers taught 111 different combinations and 23 subjects; (d) in mathematics 26 per cent taught the one subject only, 40 per cent taught one other subject, 24 per cent taught two other subjects, and 9 per cent three other subjects. 630 teachers were teaching 136 different combinations and 27 different subjects.

The conditions indicated by the Potthoff and the Indiana College Physics Teachers studies could be reduced materially by a concerted effort on the part of school administrators to schedule teachers for work in related areas. In Indiana the Commission on Teacher Training and Licensing is initiating such a program. Related teaching areas which would combine biological with physical science, or physical science with mathematics, would provide both breadth and depth of understanding and tie together the total pattern of the teacher's activity.

It is imperative that improvement be made in the science teacher training program. Specific proposals have been prepared by the A.A.A.S. Cooperative Committee on Science and Mathematics Teaching for the guidance of college and university curriculum committees and counselors.

Some of the recommendations of the committee are

1. A policy of certification in closely related subjects within the broad area of the sciences and mathematics should be established and put into practice. Specifically any combination of three of the following five subjects is recommended: biological science (including both botany and zoology), chemistry, mathematics, physics, and general science.

2. Additional courses permitting the student to complete a total of 60 semester hours should be given to courses in science and mathematics. Sixty semester hours, divided among three subjects will allow for a 24-hour major in one science subject and 18 hours in each of two others.

3. Certificates to teach general science at the 7th, 8th, or 9th grade level should be granted on the basis of a broad preparation including college courses in all the subjects concerned in general science. Because it provides activities and information relating science to everyday living in our modern technological world, because it cuts across the boundaries of specialized subject matter lines, and because it provides an opportunity for all, or nearly all, pupils to explore science phenomena and applications, the Committee recognizes general science as extremely important. It is therefore particularly desirable that a teacher be well equipped to teach such a subject.

It is further recommended that a basic program consisting of 6 to 10 semester hours in each of the beginning courses in biology, chemistry, mathematics and physics be required. In addition to these basic courses the following alternatives are recommended for certification in desired areas:

1. Additional courses permitting the student to complete a total of 18 semester hours each in three subject fields,

2. Additional courses permitting the student to complete a total of 24 semester hours each in two subject fields, or

3. Additional courses permitting the student to complete a total of 24 semester hours in one field, 18 semester hours in a second field and 6 semester hours in geology and astronomy, thus preparing for certification in three areas, one of which is general science.

To qualify for a general science certificate, a student should complete introductory courses in geology and astronomy.

Since prospective teachers need training and practice with the actual subject matter to be offered at the high-school level, it is essential that they receive adequate professionalized training in the areas in which they are to be certified.

In science and mathematics conventional undergraduate courses provide good background for the traditional high-school courses but do not provide adequately for the newer courses that are emerging to meet the general education needs of pupils or for the close correlation of science and mathematics which is needed in the education of talented science students.

Professionalized subject-matter courses should be planned co-operatively by the subject matter and education departments and taught by persons with experience in teaching the particular subject matter in the secondary school.

Evidence of the fact that the above recommendations are workable is to be found in the rules for the licensing of Indiana teachers adopted August 27, 1946, by the Indiana Commission on Teacher Training and Licensing. These rules require a comprehensive area of 40 semester hours and a restricted area of 18 semester hours. Thus in Indiana a minimum of 58 semester hours is required in the areas of licensing, which is well within the spirit of the above recommendation.

This program does not provide all the essentials for specialization in any one of the sciences, but only the initial stage in the preparation of the science and mathematics teacher. It is assumed that a minimum of an additional year will be spent in selected areas of specialization as part of his in-service training.

It is not meant to be implied that those showing a high degree of proficiency in subject matter are automatically destined to be good teachers. But, obviously, strong aptitude in subject matter, plus professional skill, good personality, and a genuine interest in young people, should be expected to comprise the best in science and mathematics teaching in the secondary school.

In-Service Education of Secondary School Teachers

The needs and plans for in-service education of elementary school teachers previously described suggest procedures equally appropriate for the improvement of instruction at the secondary

school level. Plans should be developed for using curriculum workshops, institutes, extramural content courses, summer school instruction, demonstrations, lectures, field trips, excursions and conferences for the training of secondary school science and mathematics teachers. Science and mathematics counselors, directors of teacher training, heads of departments, and supervisors for these areas should help to initiate and plan cooperatively with teachers for such activities.

One of the difficult practical problems of the teacher relates to the differentiation of instruction so that the needs of students for general education are met, while students with special interests and talents are encouraged and directed. There is need for in-service study to determine appropriate content and suitable methods for the instruction and guidance of "Major Work" classes, honor groups, science and mathematics clubs, and other existing groups and classes. In recognizing the needs of students with special talents in science and mathematics secondary school teachers need knowledge regarding the careers to which the development of such talents may lead. Thus teachers need to learn from first-hand observation the applications being made of science and mathematics in manufacturing, agriculture, mining, medicine, research, and the like. Some of this first-hand observation may be provided for by excursions and trips. Summer courses are now organized in which a university cooperates with industry, or another agency, to develop unusual study opportunities. In some such cases special courses in the sciences and mathematics are developed to present simultaneously basic concepts, newer scientific applications and an opportunity to work in close relation with both college faculties and industrial scientific staffs. Such cooperative ventures in in-service education should be encouraged.

Plans for the further education of teachers after they have been in service have not been systematically organized to serve the needs of this group. The graduate offerings in science and mathematics are usually too highly specialized and narrowly defined to serve the needs of any individual who does not intend to become a research scientist.

Teacher training institutions should provide for at least one year of graduate work in which ample courses in science and mathematics are offered to meet the needs of the teacher instead of the research scientist.

Such offerings will make it possible for the many teachers who now are forced to do their graduate work in education only, to return to their teaching fields for a majority of their graduate study. Such a step is one of utmost importance for the in-service education of teachers.

A special problem of in-service education is raised by the

necessity in the small high school to teach in the same class students who require only general education and students whose needs are more specialized. To aid the teacher with this and other problems it will be necessary to extend counseling and supervisory services to the small school.

THE CRITICAL SHORTAGE OF SCIENCE TEACHERS

The tremendously increased total enrollments of students in our high schools and the competition of higher-paying jobs of better prestige in industry have created a critical shortage of science teachers. Earlier sections of this chapter have shown that the *quality* of science teachers in terms of basic training in their disciplines tends to be grievously low. We turn now to a consideration of the *quantity* of science teachers available to accommodate the growing number of students in our schools.

In the summer of 1953, a conference on nationwide problems of science teaching in the secondary schools was held at Harvard University on the invitation of James B. Conant, then president of Harvard. A report was issued which focused attention on the seriousness of the shortage of science teachers. It was well entitled *Critical Years Ahead in Science Teaching*.

The following excerpt[9] from this report presents some data and views that should receive the careful attention of all persons who are seriously interested in good science education, for they illustrate the gravity of our present situation. Science is a part of modern life. Yet, if nothing is done to solve the problems we now face and which will otherwise grow in severity in the next decade, we will cheat our children of their right to a sound education in which science plays its proper role.

> Comparison of the supply and demand for high school science teachers over the past few years and projected changes in high school population during the next decade lead to alarming conclusions:
>
> 1. From a total in 1952–53 of 6,600,000 pupils high school enrollments in grades 9–12 will rise by 1959–60 to 9,300,000 pupils, or a 40 per cent expansion.
> 2. By 1965, high school enrollments will total between 11 and 12 million, almost double the current figures.
> 3. The number of science teachers needed in the schools will rise from 67,000 in 1952–53 to 84,000 in 1959–60. By 1965, this number will probably reach 100,000.
> 4. Continued reorganization of schools from an 8–4 distribution of years in the elementary and high schools to 6–6 or

[9] Fletcher Watson, Paul Brandwein, and Sidney Rosen (eds.), *Critical Years Ahead in Science Teaching* (Cambridge, Mass.: Harvard University, 1953), p. 10.

6–3–3 plans, where science is increasingly offered in grades 7 and 8, may enlarge the requirements for science teachers beyond the figures cited above.

5. As G.I. benefits have expired, the number of college graduates had dropped 31 per cent from a maximum of 430,000 in 1950 to slightly more than 300,000 in 1953. Graduating classes will remain near this size for the next four or five years.

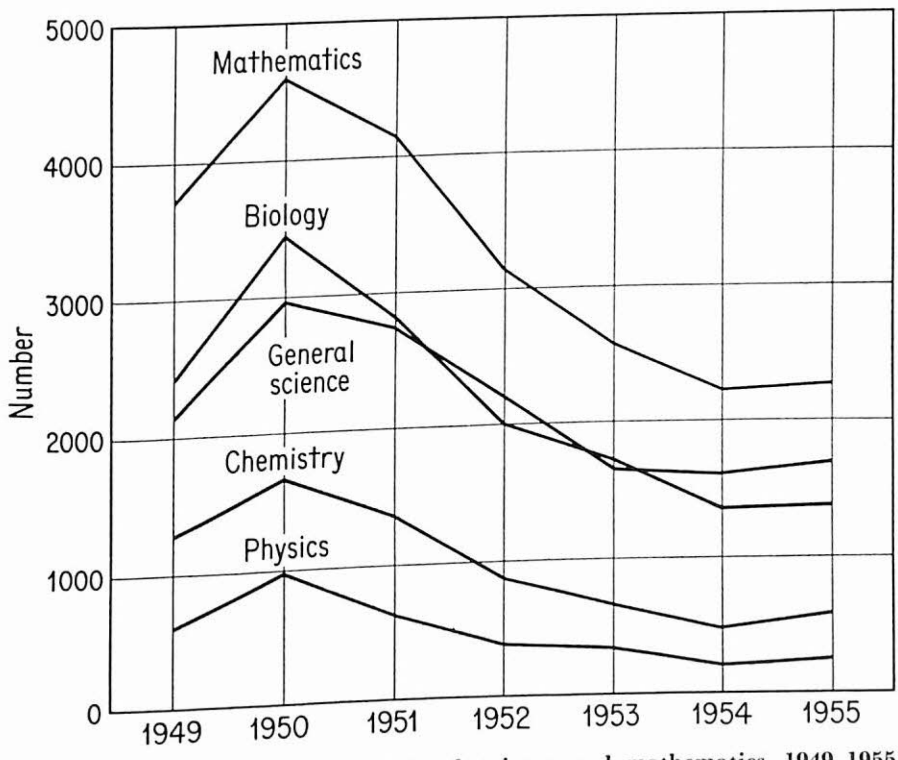
6. The percentage of college graduates qualified to teach in high school has fallen since 1950 by 36 per cent, or more rapidly than the total number of graduates.

7. The percentage of college graduates qualified to teach science has decreased even more, 48 per cent since 1950.

8. In some parts of the country and for certain science courses, especially general science, the supply of qualified teachers is now seriously deficient.

9. Already the annual need for new science teachers exceeds 7,000 and will soon approach 10,000, while at present a maximum of 5,000 potential replacements graduate from college.

When the number of graduates from the colleges and universities of the country are compared with those who are prepared to teach in the high schools, it is found that there are relatively fewer of the latter today than in previous years. The financial and other returns of other professions and occupations are



Number of graduates prepared to teach science and mathematics, 1949–1955.

draining persons away from the teaching profession. The drop is not only quantitative. There is good reason to believe that the better graduates are going where the rewards are greater and—with notable exceptions of course—the poorer students are electing education as a profession.

The drop in the numbers of graduates prepared to teach science and mathematics is particularly great. In actual numbers, there are fewer science teachers being graduated today than in 1950. There is also a shortage of trained science talent in government and industry. A reasonably capable science-trained student can therefore be fairly certain of securing a good job in industry at a much better salary than he can expect for teaching science in his own state. Naturally enough, many who might have become outstanding teachers go into industry rather than into teaching. The graph on page 363, from the Harvard report, shows the drop in numbers of graduates prepared to teach science and mathematics since 1950.

PROJECTED POPULATION AGED 14–17
AND HIGH SCHOOL ENROLLMENT

School Year	*Population 14–17 Yrs. of Age*	*Per Cent of Pop. 14–17 Yrs. of Age in School*	*Total Enrollment in High Schools*	*Non-Public School Enrollment*	*Public School Enrollment*
1945–46	8,829,000	70.1	6,187,000	565,000	5,622,000
1947–48	8,336,000	75.0	6,255,000	602,000	5,653,000
1949–50	8,234,000	77.5	6,379,000	672,000	5,707,000
1950–51	8,309,000	78.1	6,493,000	652,000	5,841,000
1951–52	8,618,000	75.6	6,518,000	675,000	5,843,000
1952–53	8,847,000	74.8	6,619,000	702,000	5,917,000
1953–54	8,989,000	75.5	6,787,000	726,000	6,061,000
1954–55	9,272,000	76.3	7,075,000	764,000	6,311,000
1955–56	9,681,000	77.0	7,454,000	812,000	6,642,000
1956–57	10,478,000	77.8	8,152,000	897,000	7,255,000
1957–58	11,112,000	78.5	8,723,000	960,000	7,763,000
1958–59	11,464,000	79.5	9,091,000	1,000,000	8,091,000
1959–60	11,570,000	80.0	9,256,000	1,018,000	8,238,000
1960–61	12,280,000	80.0	9,840,000	1,082,000	8,758,000
1961–62	12,915,000	80.0	10,335,000	1,138,000	9,197,000
1962–63	13,846,000	80.0	11,086,000	1,219,000	9,867,000
1963–64	14,100,000	80.0	11,280,000	1,230,000	10,050,000
1964–65	14,140,000	80.0	11,310,000	1,246,000	10,064,000
1965–66	14,397,000	80.0	11,517,000	1,270,000	10,247,000

Data to 1959–1960 taken from "The Outlook for School Enrollments," *Journal of Teacher Education*, 4:46, 1953; estimates from 1960 to 1965–1966 based on recorded births with 2 per cent reduction for mortality.

Source: Fletcher Watson and others, *Critical Years Ahead in Science Teaching* (Cambridge, Mass.: Harvard University Press, 1953), p. 16.

NEEDED NUMBERS OF HIGH SCHOOL TEACHERS AND SCIENCE TEACHERS, PROJECTED TO 1960

School Year	*No. of High School Teachers*	*No. of Science Teachers (Full and Part Time)*	*New Science Teachers for Replacement*	*New Science Teachers for Increased Enrollment*	*Total No. of New Science Teachers Needed**
1945–46	289,498	58,000	---	---	---
1947–48	305,739	62,000	4100	4000	8100
1949–50	324,093	65,000	4300	3000	7300
1950–51	325,143	65,000	4600	0	4600
1951–52	329,173	66,000	4600	1000	5600
1952–53	334,983	67,000	4600	1000	5600
1953–54	351,000	70,000	4700	3000	7700
1954–55	366,000	73,000	4900	3000	7900
1955–56	377,000	75,000	5100	2000	7100
1956–57	389,000	78,000	5300	3000	8300
1957–58	411,000	82,000	5500	4000	9500
1958–59	417,000	83,000	5700	1000	6700
1959–60	419,000	84,000	5800	1000	6800

*Total need for high school teachers rounded off from Table III in National Education Association, Research Division, "Teacher Forecast for the Public Schools," *Journal of Teacher Education*, 4:53, 1953.

Source: Fletcher Watson, Paul Brandwein, and Sidney Rosen (eds.), *Critical Years Ahead in Science Teaching* (Cambridge, Mass.: Harvard University, 1953) p. 17.

The foregoing two tables, from *Critical Years Ahead in Science Teaching*, show what is happening to the total enrollment in our high schools and therefore what is happening to the short supply of science teachers, who are required to keep up with the growing enrollments. Inspection of these two tables will show clearly that we are indeed facing critical years ahead. Even in 1953–1954 the need for science teachers exceeded 7,000 a year. In 1957–1958 it approached 10,000 a year. But at the present time only about 5,000 graduates prepared even by minimum standards come out of our colleges and universities each year. Many of these do not actually go into teaching, so we are facing a severe shortage right now. And the drop in graduates prepared to teach science is paralleled by the increase in need for such teachers, as demonstrated in the tables above.

What can be done about the situation and the inadequacies of training which have been discussed in previous pages? The Harvard conference issued the following seven recommendations.[10]

> From these facts and figures, we feel obliged to recommend that:

[10] Fletcher Watson, Paul Brandwein, and Sidney Rosen (eds.), *Critical Years Ahead in Science Teaching* (Cambridge, Mass.: Harvard University, 1953), p. 23.

1. Local and state school administrators make careful and realistic estimates of their future demands for science teachers ten years ahead;
2. The National Education Association or the U.S. Office of Education gather, summarize and publicize these needs;
3. Particular attention be given to the smaller schools, usually rural, from which teachers are often recruited for large cities;
4. Liberal arts and teachers colleges concerned about the quality of instruction in secondary schools immediately begin, in cooperation with professional scientific societies and associations, vigorous recruitment campaigns for secondary school teacher candidates, especially in science and in mathematics;
5. High school teachers deliberately work to encourage pupils to consider science teaching as a vocation;
6. School administrators concentrate responsibility for science teaching among a minimum number of qualified teachers;
7. Proposed curricular changes in science be carefully examined in terms of the number and ability of teachers required.

These recommendations are useful but they are mere palliatives. They are by no means capable of doing the necessary job. The only real answer to the shortage of teachers, to the low status of the profession, to the problem of securing well-trained and highly capable teachers rests on a financial base. When teacher salaries are sufficiently high to be competitive with other occupations and professions which require equal training in quantity and in quality to that which science teachers should have for work of professional quality, then, and not until then, will science teaching achieve the status and prestige it deserves and demands. Until then, our children throughout the nation will be cheated of their right to have instruction of a uniformly high level. According to the Steelman report (see page 151), "Over the period from 1920 to 1942 the national income has tripled, whereas expenditures for public education have remained nearly the same. The teacher shortage is an economic problem. In order to secure competent teachers there must be a substantial increase in the amount of money spent on education. There is adequate evidence that, as a nation, we have the financial resources to provide the necessary amount." The national income has steadily increased since 1942. Expenditures for education have increased, too, but by no means by the amount necessary to provide teachers with the salaries and conditions of work that are comparable to those in other professions.

What can be done? Fortunately, a number of things can and are being done by interested organizations. One of the most significant programs designed to improve the status of science teaching in America is that developed jointly by the Cooperative Committee on the Teaching of Science and Mathematics of the

American Association for the Advancement of Science and a committee of the Academy Conference, the central organization of state and city academies of science. The chairman of the joint committee was John R. Mayor. Its initial publication, *Science Teaching Improvement Program,*[11] was issued in 1955 and should be studied by every science teacher.

There are many demands that the individual science teacher can properly and legitimately make in order to advance the profession. But he is relatively ineffective as an individual. There are several professional societies and organizations which are organized to bring collective strength to advancing the cause of education, including science education. The science teacher should carefully consider the nature of these organizations and join those that his scrutiny determines to be validly and effectively working for sound ends.

THE PROFESSIONAL ORGANIZATIONS

The National Education Association (N.E.A.) is the largest organization of teachers in the United States today. It has many affiliated societies and branches. The National Science Teachers Association (formerly the American Council of Science Teachers) is a department of the N.E.A. for science teachers. Over the past decade this organization has grown tremendously in strength and effectiveness. It produces excellent reports and publishes a journal, *The Science Teacher,* that is growing steadily in quality. It is organized and operated on democratic principles and is becoming the most effective single voice of the science teachers of the country in developing high standards, effective education, and sound legislation related to the profession of science teaching. The reader is urged to acquaint himself with the nature and services of this organization and to join the thousands of science teachers in the nation who are working together toward advancing their cause through this organization.

The American Association for the Advancement of Science (A.A.A.S.) is the major organization that speaks for the scientists of the nation. A section of this association is devoted to advancing sound science education. The A.A.A.S. publishes two periodicals, *Science,* a weekly, and *Scientific Monthly*. The science teacher should consider the advantages of joining hands with the scientists of the nation through this organization, as well as with the National Science Teachers Association of the N.E.A.

Other national organizations that deserve the support of the science teacher and that work in his service include the following:

The Chemical Education Section of the American Chemical Society
The National Association of Biology Teachers

[11] *Science Teaching Improvement Program* (Washington: American Association for the Advancement of Science, 1955). This publication can be obtained gratis from the A.A.A.S., 1515 Massachusetts Ave., N.W., Washington 5, D.C.

The American Association of Physics Teachers
The National Association for Research in Science Teaching (membership on invitation and requiring published research)

There are others, but these are the chief national organizations and societies whose work is directed toward the advancement of science teaching.

In addition, there are regional and state organizations. One such regional organization, the Central Association of Science and Mathematics Teachers, is effective on a national scale, chiefly through its publication *School Science and Mathematics*. Most states have one or more organizations of secondary school science teachers (usually these are affiliated with national organizations) and an academy of science (generally affiliated with the A.A.A.S.).

No teacher has the time or financial resources to join all organizations. But he should find a professional home with such organizations as he feels he can support financially and through personal efforts designed to advance his profession. An organization is no more effective than the organized strength of its active members. The science teacher should not only affiliate with professional organizations, he should work in them. Those that are democratically run will provide him with plenty of opportunity to be heard on what he feels are sound goals and procedures.

Among the organizations that exist to advance the cause of education and the teacher is the American Federation of Teachers, which is affiliated with the now-combined American Federation of Labor and Congress of Industrial Organizations. The teacher should consider the work that this professional organization is doing, as well as that of the organizations already listed. In many communities and regions, the American Federation of Teachers has enrolled teachers of the highest professional caliber and has been instrumental in achieving gains for the profession that are substantial and durable.

The foregoing list of organizations is by no means complete. But it suggests the kinds that exist and includes those which are particularly concerned with the advance of science teaching. Application to these organizations will provide the reader with literature describing their nature, purposes, operations, and services. One step toward professional growth is affiliation with one or more professional organizations on the basis of careful study of the information they will provide.

KEEPING UP PROFESSIONALLY

We need not spend time in discussing the rapid strides made both in the fields of science and in professional education. The problem is how to keep up with these advances. Most science teachers are inadequately trained in one or more of the disciplines of science. It is difficult for such teachers to secure the training they need in these disciplines once they have received a bachelor's degree, for the colleges and universities generally will not give graduate credit for basic

undergraduate courses. This practice is unwise and should be changed. If the teacher of physics needs undergraduate courses in physics he should be able to get such courses and to get graduate credit for them. After all, he is a graduate, and he can hardly take the conventional advanced courses unless he has the prerequisite training. There are a few institutions which will allow graduate credit for undergraduate work when such work is determined to be of value to the teacher. The best way to ensure that their numbers will increase is to demand graduate credit for such work through the state organizations of teachers.

The problem of keeping up with the advance of science is not solved by concessions of graduate schools regarding undergraduate courses, however. For even the well-trained science teacher, say of physics, is under the necessity of keeping up with advances in that discipline. Graduate courses in physics are generally designed for the research worker in physics, not for the teacher. For the teacher to take all the advanced work he would need in physics he would have to repeat courses he had already taken and spend far more time and money than he has at his disposal. But college professors are not unreasonable. If organized requests are made for courses designed to help the well-trained teacher keep abreast of advances in the field, the courses will be offered. The best plan would be for the teachers of a state to form a committee which would work out the broad plans for the organization and administration of such courses in each of the major fields of science. The teachers should be in a position to ensure that such courses (probably offered only during the summer semesters) would be reasonably well attended, so that the courses would pay their own way.

The problem of keeping up with the advance of educational theory and practice is also quite real. The teacher who studied educational psychology ten years ago, for example, will find that the better departments and colleges of education have much to offer him that was unknown at that time. But, here, too, much that is offered in the graduate courses of education is of little value to the experienced science teacher. The typical difficulty is that colleges of education do not provide prerequisites and make advanced courses really advanced. The graduate courses generally enroll beginning graduate students along with experienced and well-trained teachers. Too often, such education courses merely rehash the obvious. What is required are graduate courses in education that penetrate critically into modern educational theory and practice and that offer the capable science teacher an opportunity to investigate and analyze data that are pertinent to his work. Such courses, like soundly designed science courses for the science teacher, will come only when the demand for them is clear and organized persistence brings them into being. The science teacher should not tolerate inept or irrelevant graduate instruction, whether it is in professional education or in science.

Going to school is not the only way—nor is it necessarily the best way—for the intelligent and self-disciplined science teacher to grow professionally. Summer work in research laboratories of industry or in field activities is an excellent way.

If the teacher has a basic background in professional education and the sciences, he can study and keep growing by using the many excellent reference materials that are available and that continue to pour from the presses. The Appendix of this book provides a briefly annotated list of reference materials for each chapter of the book. This list is quite comprehensive in its coverage of professional literature. The reference works listed for this chapter include a selection of books and periodicals that will permit the interested teacher to grow in professional maturity and to keep abreast of the advances both in science and in education.

One word, in conclusion, to the beginning science teacher. You cannot remake the world over night. You cannot expect to begin your teaching with high success by the problem approach as developed in this volume. If you begin your teaching by throwing the textbooks away and attempt to teach flexibly and functionally in the several courses which you will probably be assigned during your first year of teaching, you will probably doom yourself to failure.

Take it easy. Grow on the job. *But grow!* For the most part, your training has probably equipped you for textbook teaching *by* the field-covering approach. All right. Teach *by* the textbook and the field-covering approach, but teach as well as you know how. Study your teaching. Assess your strengths and weaknesses. Get to know students and how to work with them. Diagnose the teaching processes and learn from them. *And, if you will plan, each year, at least one major unit of instruction around clearly seen objectives which have been implemented by master plans or resource units you have prepared, you will have moved from rather rote teaching to dynamic, functional teaching in a matter of just a few years.*

Take it easy. But grow on the job. Don't sit still and become the kind of teacher who teaches as he taught twenty years ago. Teaching is a creative art. If you let yourself get into the rut of sterile teaching in the same old way, from the same old text and notes year after year, you will soon lose the thrill of watching young minds mature under your guidance. If you keep yourself abreast of advances in your sciences and in the theory and practice of sound teaching, and if you plan your instruction well, you will come to savor the satisfactions of the master teacher—the satisfactions that arise from sure knowledge that you are a master craftsman in the art of helping young people to mature intellectually, emotionally, and ethically.

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